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A STUDY OF THE SUSPENDED PARTICULATE PROBLEM IN THE DUMWAMISH BASIN

Roy Olsen, et al

Boeing Company

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A STUDY OF THE SUSPENDED PARTICULATE PROBLEM IN THE DUMWAMISH BASIN

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Air quality data accumulated since 1965 indicate the primary and secondary national air quality standards have been exceeded in the Duwamish Basin area of Seattle, Washington. The objective of this study was to determine the nature of suspended particulate and subsequently to quantify the impact of particulate sources. Ambient and source particulate was collected on fiberglass and membrane filters. Results from gravimetric, elemental, and compound analyses were combined with meteorological data for correlation and analyses. The contribution of sources for the basin was found to be 27% from natural sources, 39% transportation, and 34% point industry and multiple-area sources. Results from this study show the complexity of suspended particulate. Source tests showed a multitude of elements and compounds present and, to complicate matters, surrounding soil has been contaminated by industrial and area sources. About 35% of the particulate is directly related to road dust-type emissions.

This report was submitted in fulfillment of contract number 68-02-1499 by The Boeing Company under the sponsorship of the Environmental Protection Agency. Work was completed as of April 16, 1975.

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SECTION I

CONCLUSIONS

The Duwamish Basin area is a heavily concentrated industrial region of South Seattle, Washington. Air quality data accumulated since 1965 indicate the primary and secondary national air quality standards have been exceeded. Computer modeling studies predict only borderline compliance with 1975 secondary standards. The objective of this study was to determine the nature of suspended particulate in the Duwamish Basin and subsequently quantify the impact of specific suspended particulate sources. A network of six sites each equipped with two high volume air samplers (Hi-Vol) for simultaneous collection of particulate on fiberglass and membrane filters was operated from July through November of 1974. Results from gravimetric, elemental, and compound analyses were combined with meteorological data for correlation and analysis.

The analytical approach toward identifying particulate types is a positive step from simply making mass measurements. This approach leads toward identification of airborne particulate, giving environmental agencies an opportunity to make assessments of size distribution, chemical elements, and compound effects on public health and well being. Additionally, through positive identification of particulate, positive corrective action can be taken.

Based on the results of this rather limited study, several conclusions can be drawn:

1. The particulate loading for northerly winds was higher than southerly winds. N 102.3μg m^3, S 52.7μg m^3.

2. The highest particulate loading was found in the northerly sites and generally decreased in southerly sites, regardless of wind direction.

3. Particulate loading was highest during the work week and lower on weekends and holidays.

4. There was a measurable seasonal variation in particulate loading, with the highest loading occurring in September and early October.

5. The ashable organic concentration ranged from 8.2-44.6μg/m^3 for northerly winds. The highest concentrations were found during the work week.

6. Chloroform extracts indicated the same types of organic compounds were found from day to day and from site to site.

7. The major portion of chloroform extractable organics was identified as gasoline engine exhaust. Chloroform extracts represented less than half of the total ashable organics, the remainder being extractable with xylene, and contained highly unsaturated polyaromatic hydrocarbons.

8. Iron, manganese, zinc, and to a lesser extent, lead, correlated with each other and decreased from north to south under northerly wind conditions. Iron as an example, averaged 14μg m^3 at the norther site and 4μg/m^3 at the southernmost site. Iron, lead, and zinc were identified as major constituents in steel mill emissions.

9. Calcium, aluminum, silicon, sulfur, potassium, and titanium correlated with each other. These elements were identified in road dust, cement, and gypsum emissions. Particle size analysis indicated a homogeneous particle size distribution with a slight trend toward decreasing size from north to south.

10. The average physical particle size of the particulate is less than 3μ. Northern sites showed 66-69% of particles 0.5-3μ, whereas southern sites showed 71-75% 0.5-3μ. There were many extremely small particles (less than 0.1 μ) found in the ambient air samples.

11. The Duwamish road dust appears to be contaminated from industrial and area sources.

12. The particle classes showing the highest concentration by weight include furnace slags and spheres, fly ash, pollens and spores, concrete minerals, road dust minerals, and soot.

Particle classes	Maximum Concentration observed, wt%
Furnace slags	10
Furnace spheres	20
Furnace ash	8
Fly ash	8
Concrete minerals	10
Road dust minerals	45
Soot	20
Starch	10
Pollens and spores	20

13. Semiquantitative analysis of particulate by sources resulted in the following averages:

Natural (Pollen and spores, wind erosion, open burning biological materials)	27%
Transportation (Transportation vehicle and road dust)	39%
Industry (Point and multiple source areas)	34%

14. Particulate loading increased with the intensity and duration of temperature inversion, and also increased for approximately 200 hours after rainfall, then appeared to level off.

15. The variation in particulate concentration was largely accounted for by the variation in ashable organics and iron.

16. Results from this study indicate that suspended particulate is extremely complex. Source tests showed a multitude of elements and compounds present in each source, and to complicate matters, the surrounding soil had become contaminated from

industrial and area sources. Thus, control strategies must be more encompassing than simply controlling industrial and vehicular emissions. Consideration must also be given to cleaning up roads and parking lots and seeding barren areas. About 35 wt% of particulate is directly related to these sources.

SECTION II

RECOMMENDATIONS

To make an evaluation of what control strategies would be most effective, further work must be done in understanding the contributions of the various sources. Specific recommendations include:

1. Pinpoint specific sources more closely using directional sampling coupled with a thorough understanding of emissions.

2. Locate new site(s) north of K60 to determine background level of air reaching Duwamish on north wind days.

3. Conduct further analyses on the organic portion.

4. Through further sampling, particle sizing, chemistry and multiple correlation analyses using select meteorological criteria, determine the contribution of sources and re-entrainment.

5. Future studies of industrialized areas should be planned to cover a longer period of time so that a sufficient number of samples could be collected, analyzed and interpreted during the first phase of the study. Secondary phases would follow with redirection of sampling and/or analytical techniques to obtain the most meaningful data. Additionally, it should be recognized that meteorological conditions are an extremely important variable in a study of this type and that this is a completely uncontrollable parameter. Therefore, sufficient program time must be allowed to pick and choose the sampling days with appropriate conditions.

SECTION III

INTRODUCTION

The Duwamish Basin-Harbor Island area is a heavily concentrated industrial region of South Seattle, Washington. It is bordered on the eastern and western sides by rather abrupt valley walls rising to an average ridge height of 350 feet above mean sea level; it opens to Puget Sound through Elliott Bay on the north and to a flat agricultural area on the south.

Air quality data compiled by the Puget Sound Air Pollution Control Agency (PSAPCA) since 1965 indicate that both the primary and secondary national air quality standards have been exceeded in the Duwamish Basin-Harbor Island industrial area of South Seattle shown in table 1.

Although it appears that the air quality is improving, the area still exhibits visibility problems, soiling, and other evidence of poor air quality. The reductions in 24-hour gravimetric accumulations reported in table 1 may not be a good indicator of improved air quality since the larger particulate was the first to be removed by industrial clean-up methods. Boeing studies carried out in 1973[1] indicated that more than 50% of the airborne particulate was of respirable size of three microns or smaller.

When existing industry is in compliance with present regulations, PSAPCA estimates that 1200 tons of particulate will be emitted per year. Other sources such as vessels, trains, automobiles, home heating (excluding dust entrained by wind or traffic) presently emit 1000 tons of particulate per year. PSAPCA personnel have applied the urban diffusion model AQDM to the area, resulting in the prediction of only borderline compliance with the 1975 secondary standards.[2] Recent studies have shown that the gravel roads in the Duwamish Basin contribute 800 tons of particulate per year measuring less than 10 microns.[3] This is a significant contribution to the particulate problem which was not considered in the model above.

Several governmental and private agencies have been emphasizing the need to develop the industrial potential of the Duwamish Basin in order to ensure economic growth and long-range economic stability. Based on 1973 data (geometric mean = 68 $\mu g/m^3$), with virtually all existing point sources in compliance with Regulation I,[4] the study of the suspended particulate problem is essential to provide background data for additional control strategies.

Table 1. SUSPENDED PARTICULATE LEVELS IN THE DUWAMISH BASIN

Year	Geometric mean $\mu g/m^3$	No. of 24-hr periods exceeding 150 $\mu g/m^3$	Maximum, $\mu g/m^3$	Federal regulations for suspended particulate
1965[a]	97	15	399	Primary standard: annual
1966[a]	121	42	394	average = 75 $\mu g/m^3$; 1 day
1967[a]	99	19	241	maximum = 260 $\mu g/m^3$
1968[a]	101	20	531	Secondary standard: annual
1969[a]	108	25	472	average = 60 $\mu g/m^3$; 1 day
3/70-12/70[b]	78	9	238	maximum = 150 $\mu g/m^3$
8/71-12/71[c]	68	1	164	
1972[c]	81	5	306	
1973[c]	68	1	190	

[a]Measured at Fire Station No. 14, 3224 4th Ave. South

[b]Measured at 4600 E. Marginal Way South

[c]Measured at 4500 E. Marginal Way South

SECTION IV

STUDY OBJECTIVES AND APPROACH

OBJECTIVES AND SCOPE

The objectives of this study were to determine the nature and distribution of suspended particulate in the Duwamish Basin and to subsequently quantify the impact of specific suspended particulate sources. The scope of the program included the identification of major particulate components and sources plus an evaluation of analytical techniques. Emphasis was placed on identification of specific inorganic compounds as distinguished from organic components since this was an initial study; however, the percent total organics and some preliminary "fingerprinting" of organics were also accomplished.

APPROACH

A network of six air monitoring sites located in the Duwamish Basin was used (fig. 1). Each site was equipped with two Hi-Vol samplers for simultaneous collection of particulate on Gelman Type A, low pH, glass fiber filters and Acropor AN-800 membrane filters. The analysis scheme for the two filters is shown in figure 2.

Gravimetric and organic (low-temperature ashing and initial fingerprinting) analyses were performed on glass fiber filters. Elemental and compound (optical and X-ray diffraction) analyses were performed on membrane filters.

Results from the gravimetric analysis, elemental analysis and low-temperature ashing analysis for total amounts of organics present were combined with meteorological data in a computer program so that a multiple regression analysis could be performed for correlation and prediction of site-to-site pollution levels as a function of climatic conditions.

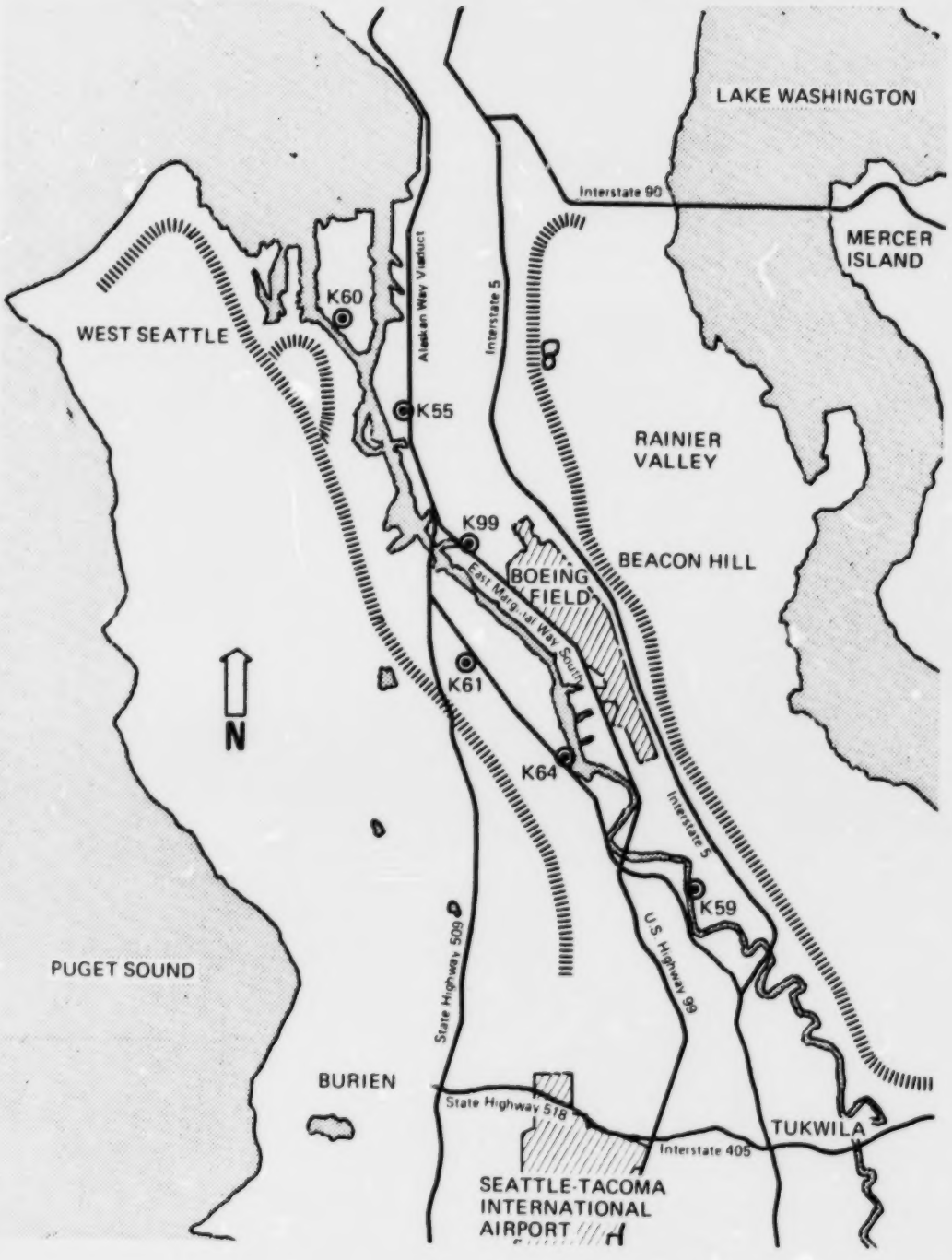


Figure 1. Duwamish Basin air monitoring sites

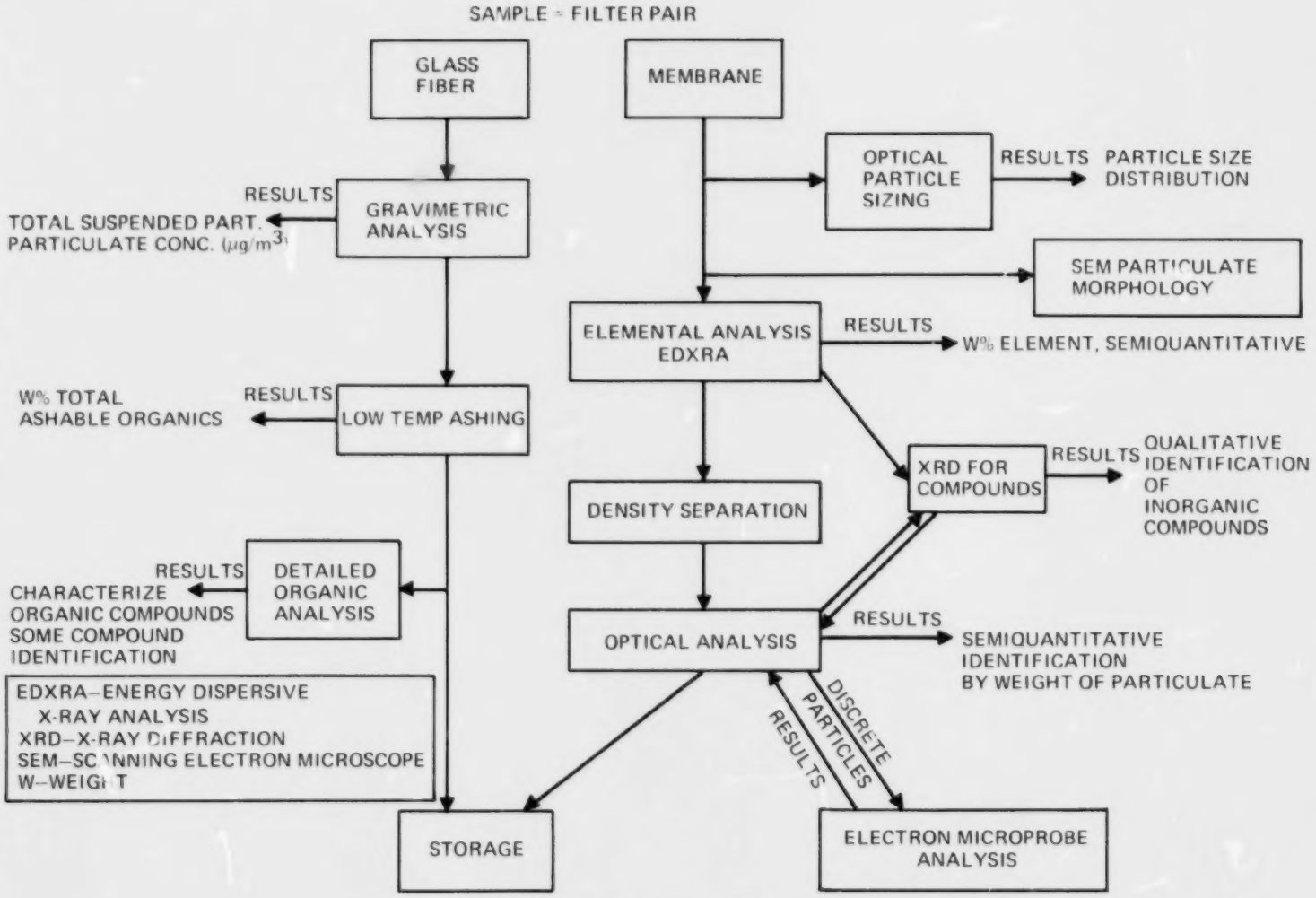


Figure 2. Sample flow-through analyses

SECTION V

PROCEDURES FOR SAMPLING AND ANALYSIS

SAMPLING

A network of six air monitoring sites located in the Duwamish Basin (fig. 1 and table 2) was used to collect airborne particulate. Each site was equipped with two Hi-Vol samplers for simultaneous collection of particulate on Gelman Type A, low pH glass fiber filters and Acropor AN-800 membrane filters. Each Hi-Vol was calibrated and operated in accordance with standard procedures.[5]

Air sampling was conducted every third day from July 10, 1974 through July 18, 1974. July 31, 1974 was the first day of predicted inversion conditions so three 8-hr sampling periods were chosen for that one day. From August 3, 1974 through November 26, 1974 sampling was conducted on every sixth day with the exceptions of October 10th, chosen for its southerly wind conditions; and October 16th, chosen because of the air stagnation alert. With the exception of July 31, all sampling periods were planned to last for twenty-four hours (00.00 to 24.00 Pacific Standard Time) so that enough particulate could be collected for all of the analyses.

Stack samples from specific point sources were collected on glass and membrane filters. Other point source samples were collected; these took the form of scrapings from towers, baghouses, etc. See table 3 for a full listing of the source samples collected.

Source test samples were treated the same, analytically, as air test samples.

GRAVIMETRIC ANALYSIS

Gravimetric analysis of the glass fiber filters was performed in accordance with standard procedures.[5] Membrane filters were not analyzed gravimetrically due to their high hygroscopic nature.

ORGANIC ASHING ANALYSIS

The weight percent of total ashable organics was determined using a low-temperature asher for all of the fiberglass samples. Low-temperature ashing (LTA) completely oxidizes organic substances from an inorganic matrix at relatively low temperatures (100°-150°C).

DETAILED ORGANIC ANALYSIS

Characterization and identification of organic compounds were performed on the glass fiber filters. The organic material was removed from the filter by Soxhlet extraction in a suitable solvent. Initial mass spectra of the total unknown indicated that further characterization

Table 2. SITE LOCATION INFORMATION

Site code	Street address	[a]UTM (zone 10) coordinates, km	Elevation above mean sea level, ft	Sampling height above ground, ft
K60	Weyerhaeuser Seattle Laboratory 3400 13th Avenue S.W. Seattle, Washington	x = 548.89 y = 5269.00	20	18
K55	Metro Duwamish Pumping Station 4500 Block E. Marginal Way S. Seattle, Washington	x = 549.77 y = 5267.74	14	34
K99	Department of Ecology Trailer 6770 E. Marginal Way S. Seattle, Washington	x = 550.63 y = 5265.75	14	16
K61	Concord Elementary School 723 S. Concord Street Seattle, Washington	x = 550.98 y = 5263.37	165	23
K64	Seattle City Light Trailer No. 1 10000 W. Marginal Way S.W. Seattle, Washington	x = 552.32 y = 5262.34	20	18
K59	Duwamish Fire Station King County Fire District No. 1 12026 42nd Avenue S. Seattle, Washington	x = 554.32 y = 5260.65	25	28

[a]UTM–Universal Transverse Mercater

Table 3. SOURCE SAMPLES

Source	Sampler	Remarks
Wood products	Hi-Vol	Outlet of cyclones used to control emissions from a sander and other woodworking machines
Gypsum products	Hi-Vol	Fugitive emissions from conveyor belt which occurred during ship unloading of gypsum rock
Harbor Island road dust	Hi-Vol	Road dust which occurred from driving a one-ton van on a gravel road in a parking lot on Harbor Island
Gasoline engine exhaust	Hi-Vol	Tailpipe emissions from a 1968 one-ton van with a gasoline engine
Diesel switch engine exhaust	Hi-Vol	Emissions from the stack of a railroad switchyard engine.
Flour Mill	Hi-Vol	Emissions from cyclone on five-mill headhouse for processing flour
Flour Mill	Hi-Vol	Emissions from a baghouse outlet used to treat the air used in wheat protein concentrate mixing and processing
Steel plant	Hi-Vol	Emissions from the high-temperature baghouse used to treat air exhausted from furnace hoods and two electric arc furnaces
Steel plant	Hi-Vol	Emissions from low-temperature baghouse used to treat air exhausted from roof of electric arc furnace building
Diesel truck exhaust	Hi-Vol	Exhaust emissions collected with a radar Hi-Vol sampling system from a diesel truck engine, 318 HP with turbo and supercharge
Diesel oil boiler	Hi-Vol	Emissions from a small (2 gallons/hour) diesel oil boiler
Cement plant	Hi-Vol	Emissions from stack
Cement plant	–	Fugitive dust collected from inside of cooling tower near south boundary of cement plant
Cement plant	–	Dust taken from electrostatic precipitator screw conveyor. This dust also goes out of the stack.
Cement plant	–	Type-One cement baghouse emission from finish mills
Road dust	Hi-Vol	Road dust generated by a truck at the Port of Seattle, Terminal 106 W.
Battery processor	Hi-Vol	Fugitive emissions from reverb furnace baghouse
Battery processor	–	Dust caught in the baghouse on the reverb furnace

and separation of the Soxhlet extracts were required for the positive identification of even a few organic compounds; thin layer chromatography (TLC) fulfilled this need and also provided a means of easily comparing the organic contents of different test filters.

A Soxhlet extraction using distilled chloroform was performed on ten glass fiber filters and a subsequent Soxhlet extraction using distilled xylene was performed on one of these filters. TLC separation was performed on each total extract; the resultant zones were compared and collected for further characterization by mass spectroscopy. The total extract was subjected to analysis by both mass spectroscopy and infrared spectroscopy.

ELEMENTAL ANALYSIS

Elemental analysis of the collected particulate was accomplished through the use of energy dispersive X-ray (EDX) fluorescence.[6] Specimens for EDX were concentrated and separated from the Acropor through an acetone extraction. A reference blank from an unused, clean membrane filter was prepared using both methods so that X-ray intensity data could be corrected for the presence of residual filter mat.

Standardization for the semiquantitative analysis was accomplished through a combination of reagent grade chemicals, National Bureau of Standards (NBS) mixtures and independent analyses of three filter specimens using atomic absorption techniques.

The raw data (X-ray intensities per element per specimen) were corrected for the presence of filter mat in the specimen. These intensities were then corrected for interelement interferences using mathematical relationships determined experimentally during calibration. The corrected intensities were converted to micrograms of element present and a weight percent calculated from the actual specimen weight. All of these calculations were computerized.

Significant errors in the semiquantitative analysis arose from large variations in the specimen weight, differences in specimen geometry, and large variations in the concentrations of the major element. Errors due to interelement interferences were minimal and mathematically corrected for most elements.

METEOROLOGICAL ANALYSIS

The meteorological analysis and summary for each sampling day were compiled by PSAPCA using the following sources for data:

1. The National Weather Service (NWS)

2. Boeing Field (King County Airport) hourly surface weather observation

3. The Environmental Meteorological Support Unit (EMSU) upper air sounding taken at Portage Bay, Seattle

4. The NWS air stagnation forecasts

5. Wind data from the PSAPCA data acquisition system

Additional air quality data used was the soiling index (coefficient of haze, COH) measured by PSAPCA at site K55.

These meteorological data were considered to be the averages for the entire Duwamish Basin area and therefore were applied to all samples taken on the same day regardless of site location.

COMPUTER ANALYSIS

Several existing computerized statistical models were investigated to determine the most valid model, or set of models, capable of predicting site to site polution levels and elemental composition of these levels as a function of meteorological conditions (prediction being the first step toward determination of point sources of ambient particulate). The programs selected for testing were BMDX64 (General Linear Hypothesis, July 27, 1965)[7] and BMD02R (Stepwise Regression, June 2, 1965).[7] Both programs were modified slightly to accommodate air particulate data since both were originally coded for biomedical analyses.

A third computer program was developed for data reduction: i.e., to convert the EDX raw data (X-ray intensities) to a usable form: weight percent of element; actual weight of element expected to be present in a normal 24-hour sample; or micrograms of element per cubic meter of air sampled. All three forms of data were input to BMDX64 and BMD02R for evaluation.

OPTICAL ANALYSIS

Optical analysis of the collected particulate using standard techniques for microscopic examination was used for semiquantitative classification of both organic and inorganic types of particulate. Two different methods of optical analysis were performed: a particulate size distribution on the filter surface, and a detailed semiquantitative compound identification-characterization of the particulate mounted on microscopic slides.

Particle size was determined using a standard filar eyepiece (10X) and Feret's diameter. The number of particles in three size ranges (0.5μ to 3μ; 3μ to 7μ; and larger than 7μ) were determined. These size ranges were chosen to correlate with results obtained in an earlier study,[1] which used an Anderson Particle Size Impactor. A single field from each membrane filter was counted to determine the size distribution with a precision of ±20% of the reported value as determined by duplicate counts.

Particulate Identification-Characterization

The particulate was separated from the membrane filter using acetone. The particulate was suspended in reagent grade monobromobenzene and pipetted into a prepared density gradient column. The density gradient was established through the use of pure liquids and

mixtures of monobromobenzene, bromoform, and di-idomethane producing an eight-layer density column. Each density gradient column was monitored by the addition of one crystal each of potassium dichromate (specific gravity = 2.61) and ammonium dichromate (specific gravity = 2.15).

The density columns chosen for detailed optical examination (particulate characterization) were drained by density level into small, clean watch glasses, labeled and evaporated to dryness in a class 100 clean bench. The dry particulate was resuspended in chlorobenzene (specific gravity = 1.1) to concentrate it in the center of the watch glass, and examined under a stereoscopic microscope to evaluate the particulate distribution. A portion of the particulate was removed with a disposable pipet and deposited on a clean microscope slide; both slide and watch glass particulate were then reexamined to insure that a representative sample had been taken. The representative specimen (on the slide) was mounted in Aroclor 5442 for examination.

Particle identification and characterization were performed using a Nikon Apophot microscope with polarizing attachments and a Carl Zeiss standard microscope with episcopic darkfield attachments. The semiquantitative analysis was based on the number and size (a real analysis) of particles of known density conforming to given optical criteria. The total particulate was divided into thirteen classes (see table 4 and fig. 3).

Electron Microprobe Analysis

Several individual particles were removed from slides for individual qualitative and semiquantitative elemental analysis on electron microprobes. An Applied Research Laboratories–EMX electron microprobe was used with wavelength dispersive X-ray analysis to determine the elemental nature of these individual particles.

SCANNING ELECTRON MICROSCOPY ANALYSIS

Representative particulates were selected at random from several ambient air membrane filters for high magnification microscopy on an Ultra Scan scanning electron microscope. This analysis was used to supplement the optical analysis in characterizing the submicron particles which were too small for optical resolution.

X-RAY DIFFRACTION ANALYSIS

Approximately 30 ambient air samples and source samples were selected for X-ray diffraction analysis. This analysis was to determine the nature of any inorganic compounds found. Macropowder samples were run on a diffractometer while micropowder samples were run on a Debye-Scherrer camera.

Table 4. PARTICLE CLASS CRITERIA

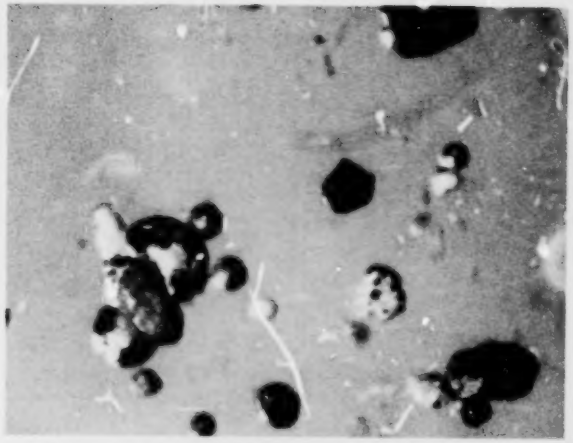
Class	Class name	Criteria for classification[a]	Error, % of reported value
1	Pollens and spores	Morphology; wall and surface structure; size	1
2	Starch	Predominantly oval or circular, transparent, smooth, colorless particle 10 20 μ in diameter. Crossed polarized light causes it to appear white with a black cross through of the grain.	1
3	Plant parts	Morphology; cell structure or organization; low density. Includes charred plant materials from open burning, plant fibers, material from food processing except starch, and naturally occurring materials.	10
4	Furnace slags	Glassy material of variable color, transparency, density, and index of refraction; no birefringence (except from strain); perfect conchoidal fracture. Two distinct morphologies: brown to opaque flakes of nearly uniform thickness; striated, multicolored clear to opaque flakes of variable thickness.	1
5	Furnace spheres	Metal and magnetite spheres; thin-shelled glass bubbles. Occurs in every density range with a wide variety of colors from transparent to opaque; 5 μ to 20 μ diameter; no birefringence. Black spheres have same optical characteristics as soot so classified with respect to density and size.	20
6	Furnace ash	Irregular morphology; generally opaque; variable color; no birefringence. Surface often appears to be composed of numerous small particles. (If specific gravity 2.2, then distinguished from charred plant parts and tire rubber by glassy formations.)	10

[a]See references 8 through 18 for a more detailed discussion of particulate classification criteria.

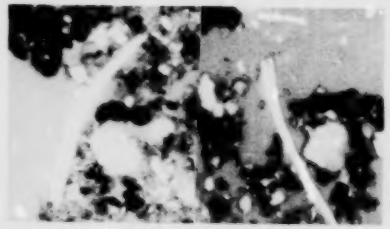
Table 4 (concluded). PARTICLE CLASS CRITERIA

Class	Class name	Criteria for classification[a]	Error, % of reported value
7	Fly ash	Large particles (10 μ); spheroidal; restricted to transparent yellow to oranne "bulbs" with pockmarked surface.	1
8	Abrasive dusts	Restricted to positive identification of garnet abrasives and silicon carbide. (Many types of industrial abrasives are difficult to distinguish from locally common natural minerals.)	0
9	Concrete minerals	Restricted to cement cinders (specific gravity 3.0) and hydrated calcium silicates, ferrites, aluminates, sulfates, and oxides (specific gravity 2.4) includes gypsum and calcite. Hydrated particles may resemble clay minerals.	20
10	Road dust	Birefringence, refractive index and density of common minerals (e.g., quartz, hornblende, olivine, feldspars, and common clay minerals).	10
11	Soot (oil)	Black spheres (specific gravity 2.2), size (1 μ to 25 μ).	30
12	Tire rubber	Morphology (black coned cylinders with poorly defined edges at 500X and no predominant ordering).	10
13	Other	All items not fitting the criteria for classes 1 through 12 and not representing a significant portion of the total specimen. Examples: diatoms, metal turnings, moth scale, glass, and nylon fibers not morphologically attributable to the sampling filters used.	

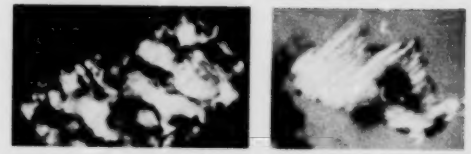
[a]See references 8 through 18 for a more detailed discussion of particulate classification criteria.



5. FURNACE SPHERES, 100X

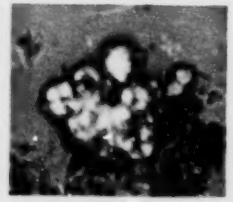


3. PLANT PARTS, 120X

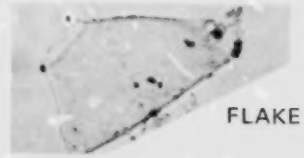


CINDER HYDRATED

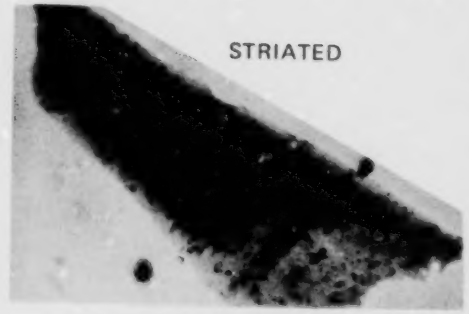
9. CONCRETE MINERALS, 500X



2. STARCH, 500X



FLAKE



STRIATED

4. FURNACE SLAGS, 500X

7. FLY ASH, 500X

6. FURNACE ASH + Fe_3O_4, 200X

Figure 3. Representative photographs of some particle classes (Numbers refer to particle class)

SECTION VI

RESULTS AND DISCUSSION

SAMPLING

A total of 198 glass fiber and 202 membrane filters were collected.

GRAVIMETRIC ANALYSIS

All gravimetric data are tabulated by date, meteorological conditions and geographic location in tables 5 through 7.

Figure 4 reveals the seasonal variation of the average particulate concentration, $\mu g/m^3$. A three-point smoothing function has been applied to the data from tables 5 through 7 to reduce the scatter caused by the other variables (degree of vertical ventilation, wind direction, and type of day). This figure clearly indicates a gradual increase of airborne particulate beginning in early July and extending through late September. There is then a gradual decrease in particulate loading until mid-October; the decrease becomes quite pronounced with the onset of the autumn rainy season.

Figure 5 illustrates the average particulate concentration as a simultaneous function of wind direction and geographic location (sites are listed north, K60, to south, K59). These curves indicate that the highest particulate loading occurs in the north end of the Duwamish Basin. This may be attributed to the high average density (specific gravity) of the collected particulate (see Optical Analysis) and/or the location of major sources of particulate in the vicinity of the northernmost site, K60.

The particulate loading for northerly winds is consistently higher than that for southerly winds; this may be attributed to the degree of vertical ventilation and/or the average wind speed. The southerly winds were more frequently associated with rain (implying good vertical ventilation) than the northerly winds which were frequently associated with inversion conditions. The southerly wind speeds were generally higher than the northerly wind speeds, resulting in a much greater mixing depth, and more instability providing better dispersion of particulate throughout the sampling network.

The individual curves for predominant wind direction yield some information concerning general locations of major sources of airborne particulate. The northerly winds indicate that particulate sources exist north of K60 and between K61 and K64. The southerly winds indicate major particulate source(s) between K61 and K99 and minor source(s) between K55 and K60. The mixed winds generally fall between the particulate loading for the north and south winds, displaying characteristics of both; there is no obvious explanation for the high average particulate concentration (PC) at K99 and K64. These observations are summarized in figure 6 which shows the general geographic locations of particulate sources. Figure 7 illustrates the effect of the day of the week on the average particulate

Table 5. METEOROLOGICAL AND GRAVIMETRIC DATA FOR GENERALLY NORTHERLY WIND DAYS

Date	Meterological data		Soiling[a] index COH	Gravimetric data Particulate concentration, $\mu g/m^3$ Sites listed north to south						Daily arith. ave.[b]
	Wind dir. and speed, knots	Inversion		K60	K55	K99	K61	K64	K59	
7-13[h]	N at 11	Yes[d]	0.4	Abort	Abort	55.6	40.2	60.4	43.2	49.8
7-18	NW at 5	No	0.5	94.7	61.8	58.2	26.3	30.4	32.6	50.7
7-25	NW at 12	Yes	0.5	135.3	103.6	98.8	49.6	96.1	63.7	91.2
7-28[h]	N at 10	Yes[d]	0.2	49.7	58.0	52.0	52.9	78.7	58.6	58.3
7-31m	N at 2	Yes	Abort	185.2	105.6	118.7	100.9	91.2	77.7	113.2
7-31n	N at 8	Yes	Abort	222.2	106.4	127.7	117.9	239.2	105.6	128.0
7-31e	N at 6	No	Abort	213.8	101.5	95.8	84.0	103.2	107.0	117.6
8-3[h]	NW at 8	Yes[d]	Abort	56.5	61.7	64.0	58.4	77.3	27.3	57.5
8-9	NW at 8	Yes	Abort	129.8	84.9	137.6	61.0	65.2[c]	67.5[c]	91.0
8-15	NW at 7	Yes	0.6	91.2	76.1	94.8	77.5	81.8[e]	82.0	83.9
8-21	NW at 5	No[d]	0.7	130.3	92.4	65.0	61.7	97.7	68.9	86.0
8-27	N at 6	Yes	1.3	186.7	176.4	Abort	93.0	113.5	100.4	134.0
9-2[h]	NW at 10	Yes[d]	0.8	92.1	114.7	Abort	86.8	96.8	92.1	96.5
9-14[h]	NW at 6	Yes[d]	1.5	118.4	132.8	115.2	92.0	105.0	89.5	108.8
9-20	NW at 9	Yes	1.1	257.4	175.6	185.9	137.9	198.6	123.3	179.8
9-24	NW at 9	Yes	1.3	195.2	171.3	180.0	118.9	155.3	115.8	156.1
10-16	NW at 5	Yes	2.6	243.7	207.6	Abort	151.9	159.6	120.9	176.7
11-1	NW at 5	No	1.1	86.0	55.8	54.6	77.6	47.5	55.2	62.8
11-13	NW at 4	Yes	0.8	117.1	79.5	76.0	89.9	48.1	Abort	70.8

Table 5 (concluded). METEOROLOGICAL AND GRAVIMETRIC DATA FOR GENERALLY NORTHERLY WIND DAYS

Arithmetic averages	Gravimetric data particulate concentration, $\mu g/m^3$ Sites listed north to south					
	K60	K55	K99	K61	K64	K59
All days[f] (number of data points)	144.7 (18)	109.2 (18)	98.7 (16)	83.1 (19)	102.4 (19)	75.8 (19)
Workdays (Monday through Friday)[g] (number of data points)	163.5 (14)	114.2 (14)	107.8 (12)	89.2 (14)	109.1 (14)	80.7 (14)
Nonworkdays (Sat., Sun., and holidays)[g] (number of data points)	79.2 (4)	91.8 (4)	71.7 (4)	66.1 (4)	83.6 (4)	62.1 (4)
Difference: workdays minus nonworkdays	84.3	22.4	36.1	23.1	25.5	18.6
% difference (workdays)	51%	20%	33%	26%	23%	23%

Note: 7-31 is one day consisting of three 8-hour sampling periods: Morning (m), noon (n), and evening (e).

[a] Measured by tape sampler at site K55

[b] Plotted in figure 4; aborts ignored

[c] Unintentional sample period of 37 hours

[d] No soundings were taken

[e] Unintentional sample period of 48 hours

[f] Plotted in figures 15-17

[g] Plotted in figure 8

[h] Nonworkday

Table 6. METEOROLOGICAL AND GRAVIMETRIC DATA FOR GENERALLY SOUTHERLY WIND DAYS

Date	Meteorological data		Sodar index COH	Gravimetric data Particulate concentration, $\mu g/m^3$ Sites listed north to south						Daily arith. ave.[b]
	Wind dir. and speed, knots	Inversion		K60	K55	K99	K61	K64	K59	
7-4	SW at 7	No[c]	0.2	27.7	18.8	Abort	18.5	Abort	24.9	22.5
7-16	SE at 7	Yes	0.9	89.6	65.6	72.4	33.6	32.2	Abort	58.7
7-22	SE, SW at 10	Yes	0.4	67.8	49.2	100.7	27.2	24.4	26.9	49.4
9-8	SE, SW at 14	No[d]	0.3	63.1	68.4	65.0	Abort	Abort	Abort	65.5
10-2	S at 10	No	0.5	68.7	71.8	115.6	37.0	54.4	38.1	64.3
10-10	SW, SE at 8	No	0.9	81.9	70.0	114.6	49.5	47.8	49.8	68.9
10-26	SE at 4	Yes[c]	1.7	124.7	93.8	Abort	108.8	76.0	69.8	94.6
11-7	SE at 5	No	1.1	44.4	43.4	36.4	26.5	19.2	26.5	32.7
11-19	SE at 10	No	0.6	34.6	36.3	23.8	18.1	18.6	26.0	26.2
11-25	SW at 7	No	0.6	79.1	47.1	77.0	40.7	32.3	41.4	52.9
Arithmetic average[d]				68.2	56.4	75.7	40.0	38.1	37.9	
(Number of readings)				(10)	(10)	(8)	(9)	(8)	(8)	

[a]Measured by tape sampler at site K55.

[b]Plotted in figure 4, aborts ignored.

[c]No soundings were taken.

[d]Plotted in figure 5.

Table 7. METEOROLOGICAL AND GRAVIMETRIC DATA FOR DAYS HAVING VARIABLE WIND CONDITIONS

Date	Sodar[a] index COH	Inversion	Particulate concentration, $\mu g\ m^3$, sites listed north to south						
			K60	K55	K99	K61	K64	K59	Daily arith. ave.[b]
7-10	0.3	No	50.3	31.3	43.0	17.7	Abort	20.0	32.5
9-26	0.5	No	138.2	82.0	163.4	65.4	83.7	62.0	99.0
10-8	1.8	Yes	180.1	140.2	Abort	130.3	234.9	109.5	159.0
10-14	1.6	Yes[c]	Abort	118.8	158.4	107.1	144.7	87.2	123.2
10-20	0.5	No[c]	33.7	40.0	Abort	28.1	21.7	27.5	25.2
Arithmetic average, $\mu g\ m^3$[d]			100.6	82.5	121.6	69.7	121.2	61.2	
(Number of readings)			(4)	(5)	(3)	(5)	(4)	(5)	

[a] Measured by tape sampler at site K55.

[b] Plotted in figure 4, aborts ignored.

[c] No soundings were taken.

[d] Plotted in figure 5.

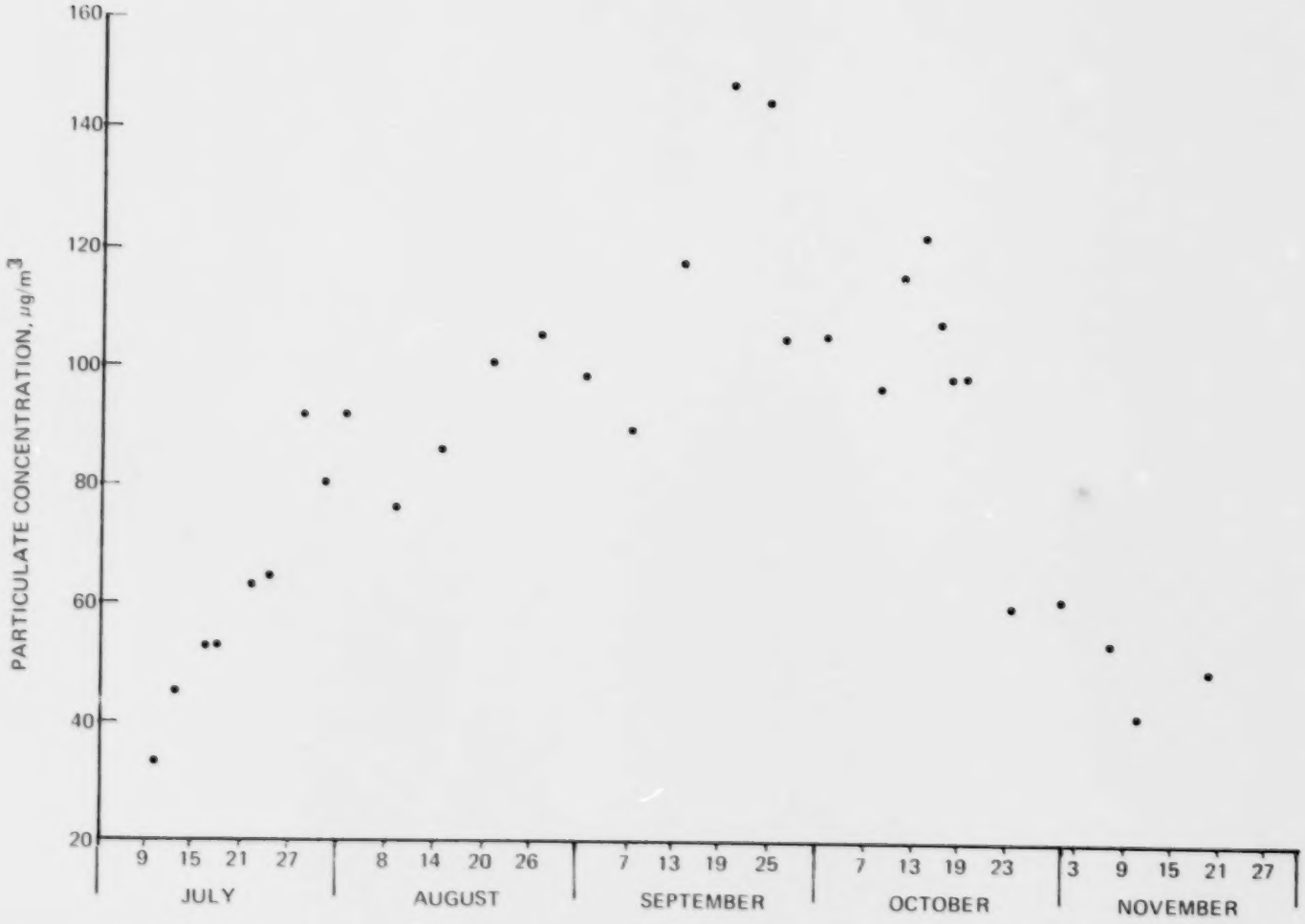


Figure 4. Particulate concentration, daily arithmetic average with three-point smoothing function applied

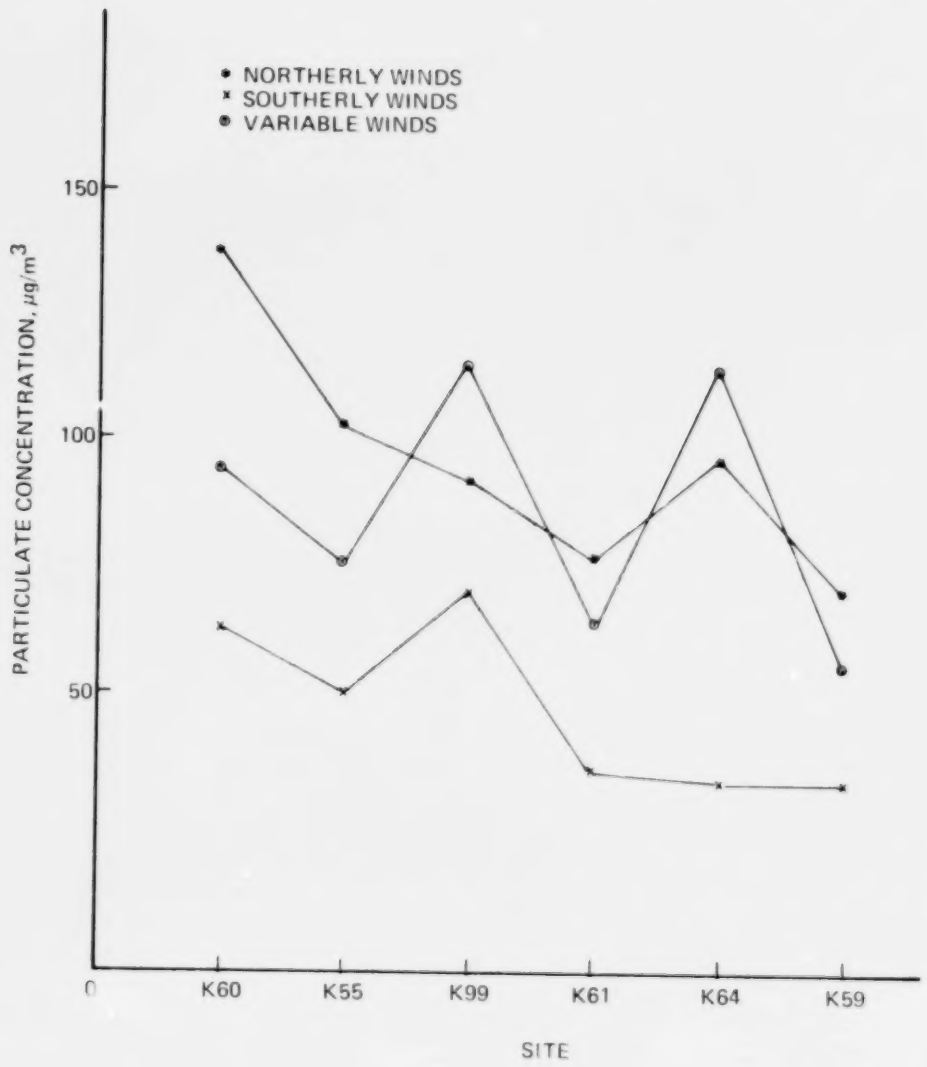


Figure 5. Particulate concentration, arithmetic averages by site and wind direction

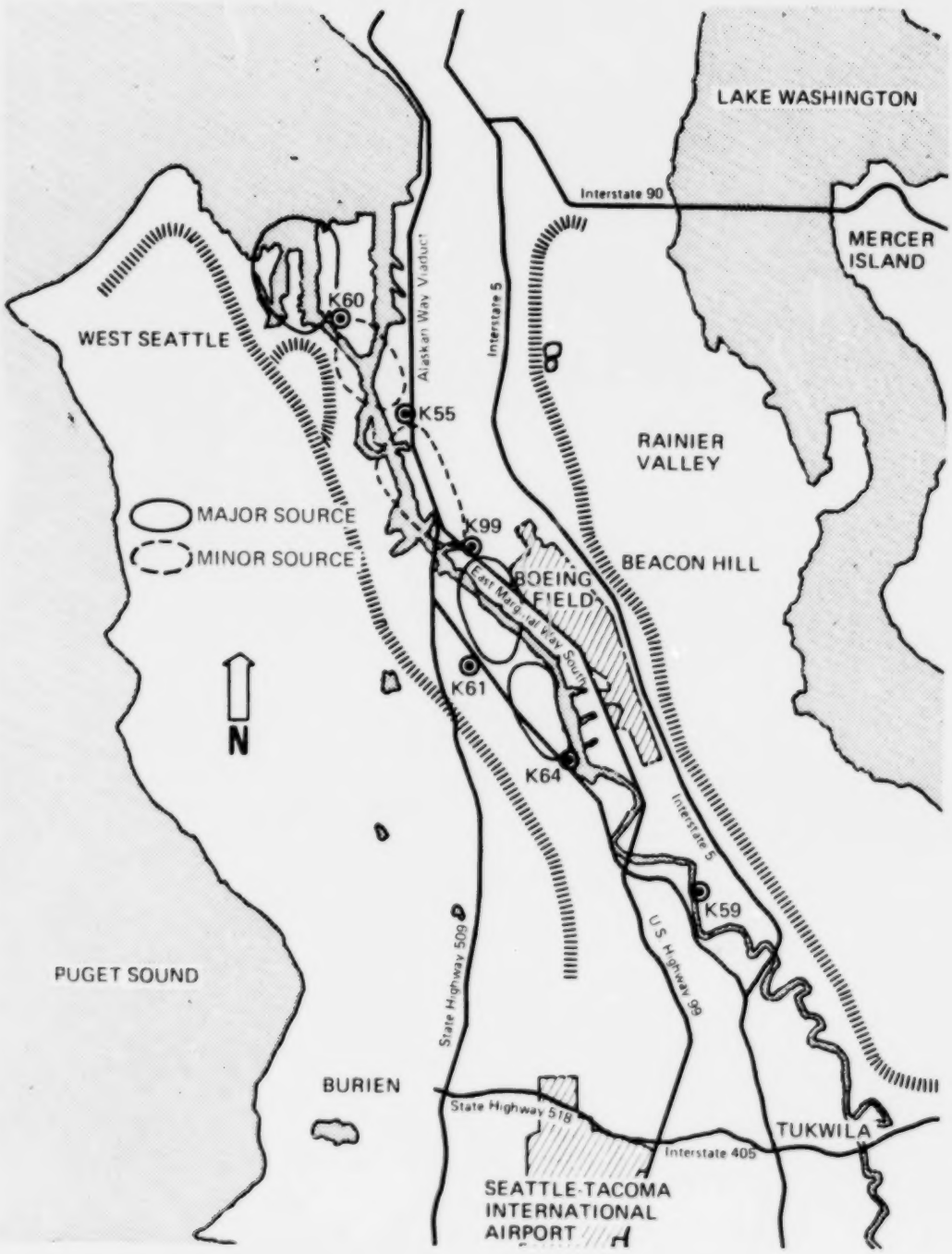


Figure 6. Geographic locations of particulate sources

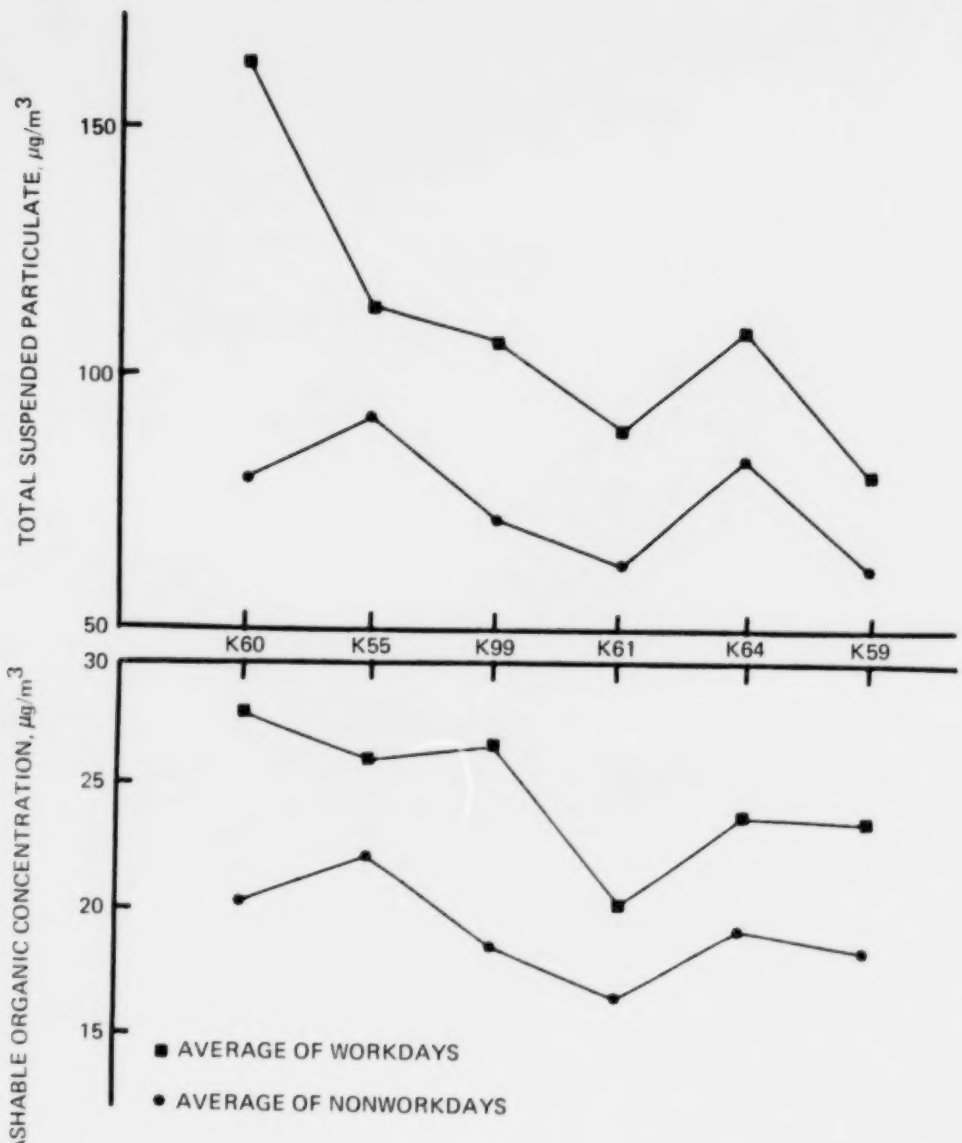


Figure 7. Concentration of particulates and ashable organics, arithmetic averages by site and day of week (northerly winds only)

concentration for northerly winds. Except for K60 the differences between the average PC on workdays and nonworkdays are fairly constant, suggesting that the differences could be attributed to nonnatural sources, i.e., industry and/or transportation. Some suppositions that may be gleaned from close scrutiny of the PC curves in this figure are: (1) there may be industrial sources north of K60 that emit particulate only five days a week (also supported by optical analysis data from density separations); (2) the area between K55 and K99 may contain a minor source of particulates; (3) there may be sources between K61 and K64 that emit particulate seven days a week.

Figure 7 also illustrates the effect of the day of the week on the average concentration of ashable organics. The average workday concentration is higher than the average nonworkday concentration for ashable organics and for particulate loading.

ORGANIC ASHING ANALYSIS

Results cover all sampling days through October 10, 1974, plus twelve source test filters. Ambient air sample results are tabulated by weight percent in table 8, while source test filter results are listed in table 9. The relationship between the particulate concentrations observed on workdays and nonworkdays (for generally northerly wind conditions) prompted a similar interpretation for the concentration of ashable organics in ambient air test filters (see table 10 and fig. 7). The similarities between the two sets of curves indicate that ashable organics play a large role in the level of airborne particulate. In addition, the low averages at K61 may be attributed to its geographic location - away from areas of large traffic volume; and the positive slope of the workday curve between K55 and K99 may indicate that transportation is a major contributor to the ashable particulate.

DETAILED ORGANIC ANALYSIS

Soxhlet Extraction

Seven ambient air test filters (six sites sampled on July 25, 1974, and site K99 sampled on August 21, 1974) were extracted using the Soxhlet method with the solvent chloroform; K99 (8-21-74) was subsequently Soxhlet extracted with the solvent xylene. These results are summarized in table 11 where it can be seen that less than half of the total ashable organics (as determined by LTA) are soluble in chloroform while the remainder are soluble in xylene.

Two source test filters were Soxhlet extracted using chloroform. These were the gasoline engine exhaust (yielding 3.3 mg of organic material) and the diesel oil boiler (yielding 0.3 mg of organics, which is less than the yield of the reference blank, 0.9 mg; less than the accuracy, ±0.4 mg, of the analytical balance used; and less than the minimum amount of material required for any of the subsequent analyses). The gasoline engine exhaust was not analyzed gravimetrically so no reliable LTA data are available; therefore the amount of chloroform extractable organics in this source test cannot be related to the amount of total ashable organics present. The amount of chloroform extractable organics (1% by weight) in the diesel oil boiler is much less than LTA data (70% by weight) indicate. This discrepancy

Table 8. TOTAL ASHABLE ORGANICS: AMBIENT AIR TEST FILTERS
(percent by weight)

Date	K60	K55	K99	K61	K64	K59
7-4	26.3	33.1	Abort	30.4	Abort	34.2
7-10	21.4	26.7	27.0	27.4	Abort	32.7
7-13	Abort	Abort	25.5	27.7	27.5	32.8
7-16	24.6	29.9	31.3	35.0	40.1	Abort
7-18	15.0	21.5	28.0	31.3	32.7	36.7
7-22	18.0	21.1	25.4	28.2	30.9	32.2
7-25	10.8	12.8	20.9	16.9	17.8	21.2
7-28	28.4	21.9	25.2	29.3	19.1	27.4
7-31m	19.6	28.0	29.4	26.6	25.5	31.0
7-31n	17.4	29.3	28.7	26.0	18.0	33.2
7-31e	14.2	29.6	25.3	15.7	17.2	20.1
8-3	21.5	22.9	16.0	23.2	20.2	27.2
8-9	16.6	24.8	20.9	19.1	22.7	27.0
8-15	19.1	27.9	22.3	23.4	19.8	24.1
8-21	13.3	22.3	24.2	27.6	23.6	29.8
8-27	21.4	22.4	22.3	25.2	23.4	27.6
9-2	25.4	21.7	Abort	19.6	21.4	24.1
9-8	26.8	20.1	26.0	5.8	14.9	Abort
9-14	26.5	28.0	32.3	28.4	27.2	30.3
9-20	16.0	19.1	23.5	23.3	18.1	26.5
9-24	18.3	19.6	24.8	26.8	22.8	29.2
9-26	18.9	19.8	19.4	23.8	19.5	27.9
10-2	20.0	19.5	No data	24.4	17.0	25.6
10-8	26.5	35.2	Abort	34.2	30.4	37.8
10-10	28.8	29.6	No data	32.5	34.3	35.8

Table 9. TOTAL ASHABLE ORGANICS: SOURCE TEST FILTERS

Source	Total suspended particulate, gm	Total ashable organics, wt %
Gypsum ship unloading	2.4788	7
Gypsum ship unloading	2.0291	7
Diesel switch engine exhaust	0.2080	2
Harbor Island road dust	3.9781	2
Gasoline engine exhaust	(0.2421)[a]	(9)[a]
Steel plant hi-temp baghouse	0.0525	43
Steel plant low-temp baghouse	0.0120	58
Diesel oil boiler	0.0292	70
Flour Mill five-mill cyclone	0.1732	72
Flour mill baghouse	0.0712	66
Cement plant stack	0.1665	11
Road dust	1.87	7

[a]No gravimetric analysis was performed on this filter so total suspended particulate and total ashable organics are estimates.

Table 10. CONCENTRATION OF ASHABLE ORGANICS[a]–NORTHERLY WINDS
(micrograms/cubic meter)

Date	K60	K55	K99	K61	K64	K59
Workdays						
7-18	14.2	13.6	16.3	8.2	9.9	12.0
7-25	14.6	13.3	20.6	8.4	17.1	13.6
7-31m	36.3	29.6	34.9	26.8	23.2	24.0
7-31n	38.6	31.2	36.6	30.6	43.0	35.1
7-31e	30.4	30.0	24.2	13.1	17.8	21.5
8-9	21.5	21.0	28.8	11.6	14.8	18.2
8-15	17.4	21.2	21.1	18.1	16.0	23.0
8-21	17.3	20.6	15.7	17.0	23.0	20.5
8-27	39.9	39.5	8.8	23.4	26.6	27.7
9-20	41.2	33.5	43.7	32.1	35.9	32.7
9-24	35.8	33.6	44.6	31.9	35.4	33.8
Nonworkdays						
7-13	Abort	Abort	14.2	11.1	16.6	14.2
7-28	14.1	12.7	13.1	15.5	15.0	16.0
8-3	12.1	14.1	10.2	13.5	15.6	13.6
9-2	23.4	24.9	Abort	17.0	20.8	22.2
9-14	31.4	37.1	37.2	26.1	28.6	27.1
Arithmetic averages						
Workdays[b]	27.9	26.1	26.9	20.1	23.9	23.8
Nonworkdays[b]	20.3	22.2	18.7	16.7	19.3	18.6
All days	25.9	25.1	24.7	19.0	22.5	22.2

[a]Concentration of ashable organics = (Particulate concentration x % ashable organics)/100

[b]Plotted in figure 7

Table 11. ORGANIC CONTENT BY SOXHLET EXTRACTION

Site	Date sampled	TSP,[a] mg	TAO,[b] wt %	Chloroform extractable organics		
				gm	% TSP[a]	% TAO[b]
K60	7-25-74	133	11	4.2	3.2	29
K55	7-25-74	97	13	2.5	2.6	20
K99	7-25-74	103	21	4.6	4.5	21
K99	8-21-74	64	24	9.7	10.7	45
K99	8-21-74	64	24	5.5[c]	15.3[c]	55[c]
K61	7-25-74	50	17	2.7	5.4	32
K64	7-25-74	108	18	6.6	6.1	34
K59	7-25-74	66	21	4.4	6.7	32

[a]TSP = 0.75 x total suspended particulate as determined from gravimetric analysis

[b]TAO = Total ashable organics as determined from low-temperature ashing

[c]Xylene extraction which followed a chloroform extraction of the same filter sample.

Note: Chloroform extraction followed by xylene extraction of the same filter sample accounts for 100% of TAO as determined by low temperature ashing.

may be explained by the presence of a large amount of xylene soluble organics or by the presence of a large amount of elemental carbon which is not soluble in chloroform but is oxidizable (LTA).

Infrared Spectroscopy

All of the chloroform extracts produce infrared spectrograms indicating varying amounts of a few types of molecular bonds which are predominantly associated with aliphatic hydrocarbons and aliphatic carbonyl-containing compounds (esters and acids). The xylene extract (K99, 8-21-74) contains some aliphatic hydrocarbons and esters but is primarily composed of aromatic hydrocarbons (substituted and/or polynuclear). See figures 8 and 9 for absorption band assignments. The chloroform-extracted reference blank produced an absorption band associated with silicones; this band is not called out in the spectrograms as it is felt that contributions to it can be attributed entirely to the glass filter.

Thin Layer Chromatography (TLC)

Figure 10 shows that TLC is a more sensitive method for characterizing trace quantities of organic materials than infrared spectroscopy. Close scrutiny of the TLC overlays of the chloroform extracts reveals (1) that all of the ambient air test samples contain many of the same types of organic materials as the source test sample of the gasoline engine exhaust; (2) that the TLC patterns of K99 (8-21-74), K99 (7-25-74) and K59 (7-25-74) are identical; and (3) that the TLC patterns from K64, K61 and K55 (all from 7-25-74) are also identical.

These results indicate that the same organic materials are present from day to day (from (2) above); and site to site (from (2) and (3) above) on the same day. Therefore, a representative filter (such as K59, 7-25-74) was chosen for intensive study by mass spectroscopy.

The xylene extract of K99 (8-21-74) was chromatographed using various solvents and combinations of solvents. Figure 11 illustrates these results and the various degrees of separation obtainable.

Mass Spectroscopy

Mass spectra were obtained from all of the Soxhlet extracts listed in table 11, plus the chloroform extract of the source test of the gasoline engine exhaust (figs. 12 and 13). In addition, mass spectra were obtained from TLC separations of the chloroform extracts from K59 (7-25-74) and the gasoline engine exhaust (figs. 14 through 17 and table 12).

The outstanding feature in all of the low-resolution mass spectra of the chloroform extracts is the typical fragmentation pattern of high molecular weight aliphatic hydrocarbons. These are the peaks between 40 and about 150 mass units corresponding to ion formulas C_nH_{2n+1} and C_nH_{2n-1} with smaller peaks at C_nH_{2n}. The peak intensities become progressively smaller with increasing mass for this series. The parent peaks of the many possible hydrocarbons that contribute to these peaks are either very small or do not appear at all. The similarities between the chloroform extracts of the gasoline engine exhaust and

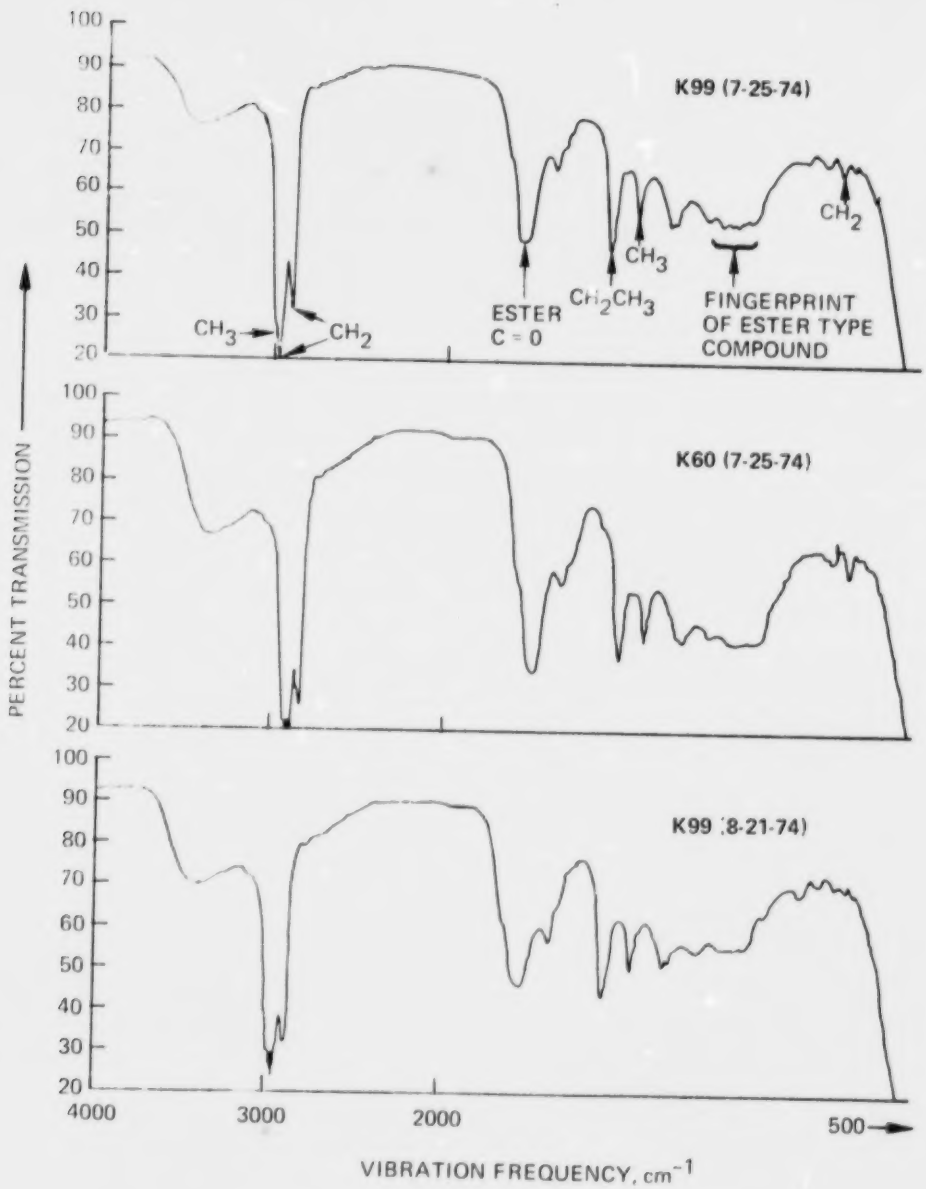


Figure 8. Infrared spectrograms of chloroform extracts

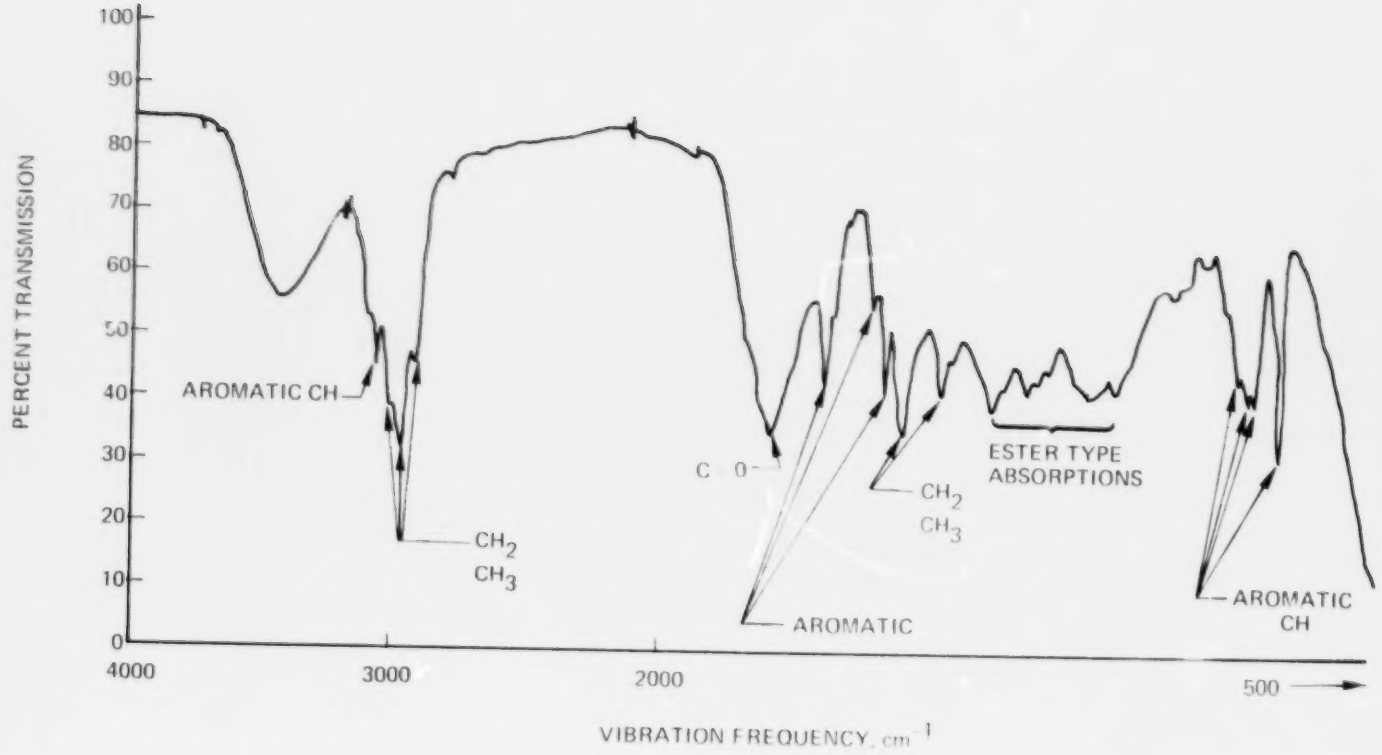


Figure 9. Infrared spectrogram of xylene extract from K99 (8 21 74)

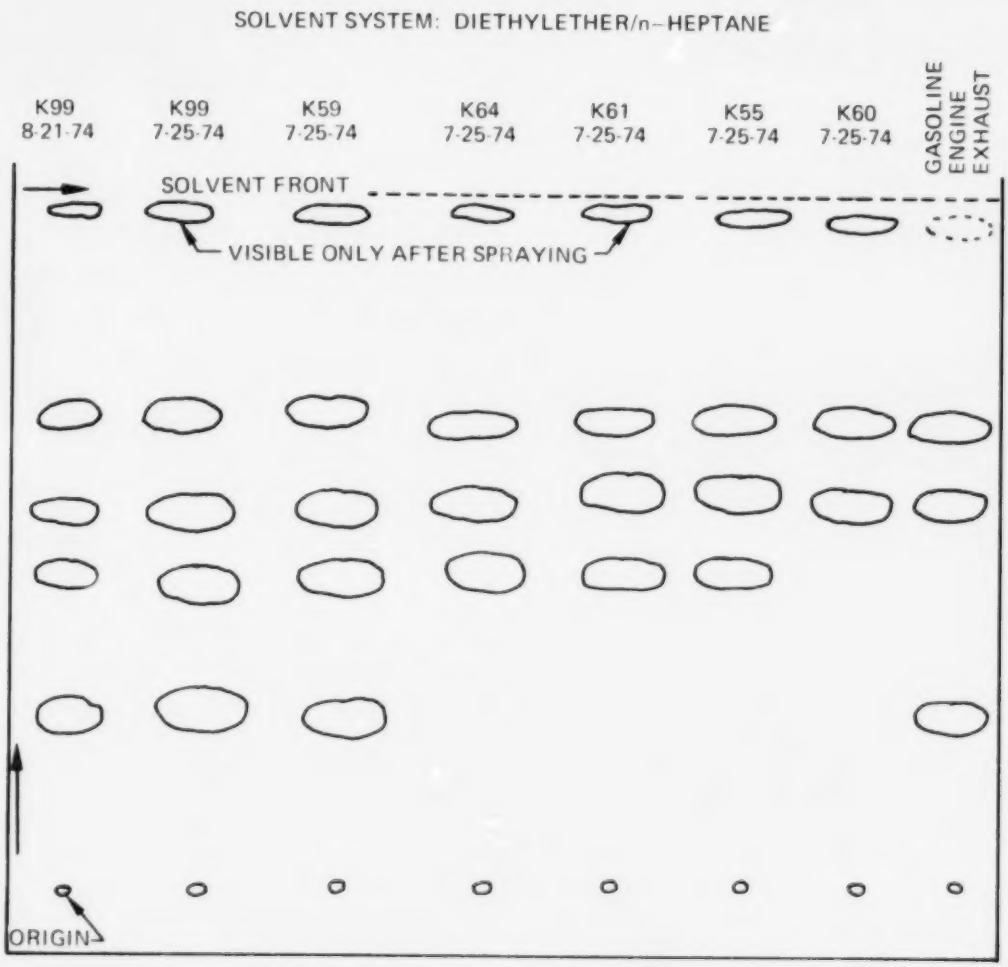


Figure 10. TLC overlay of chloroform extracts

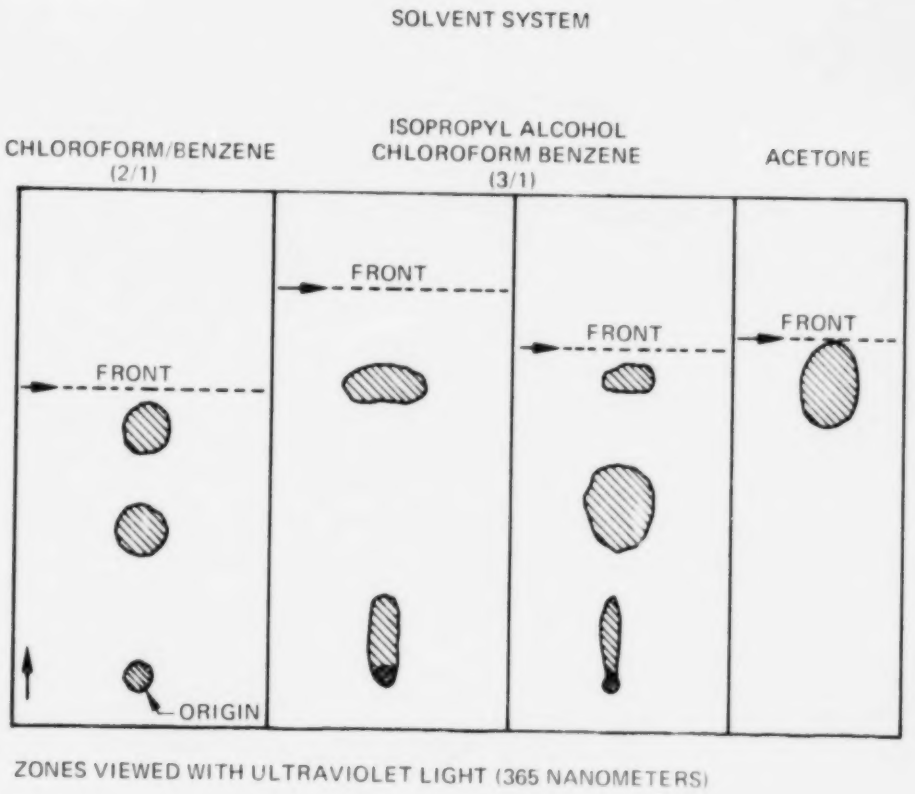


Figure 11. TLC overlays of xylene extract from K99 (8-21-74)

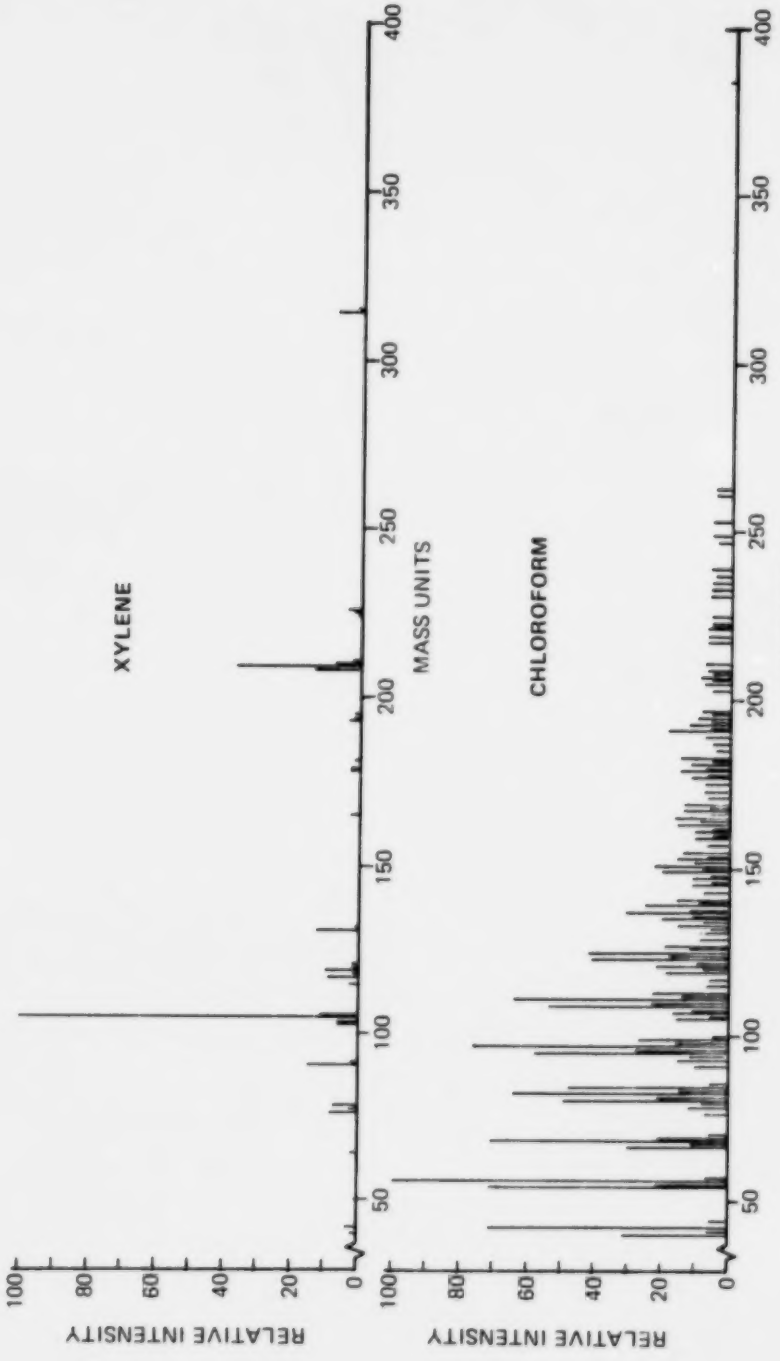


Figure 12. Normalized bar graphs of mass spectra obtained from extracts of K99 (8-21-74)

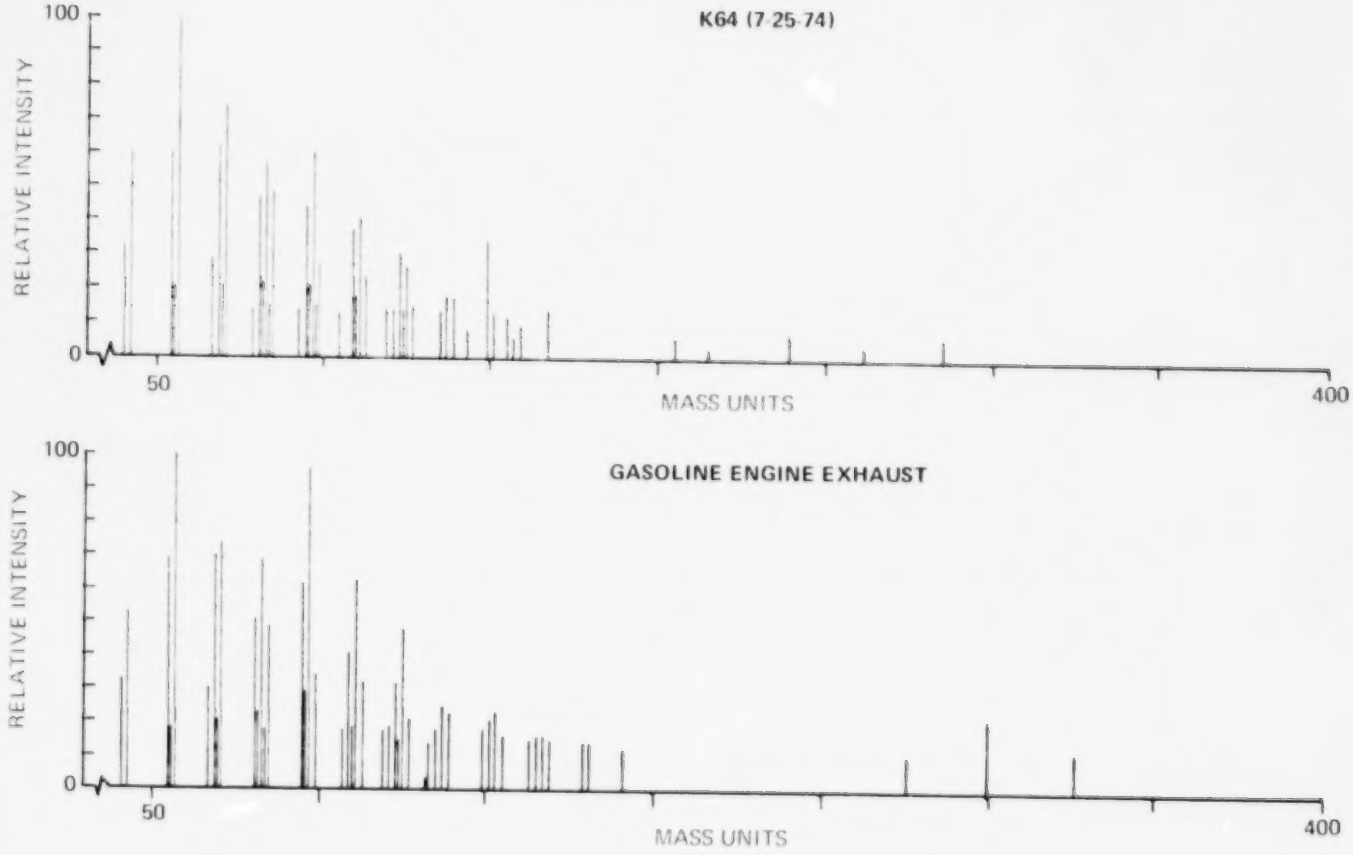


Figure 13. Normalized bar graphs of mass spectra obtained from total chloroform extracts

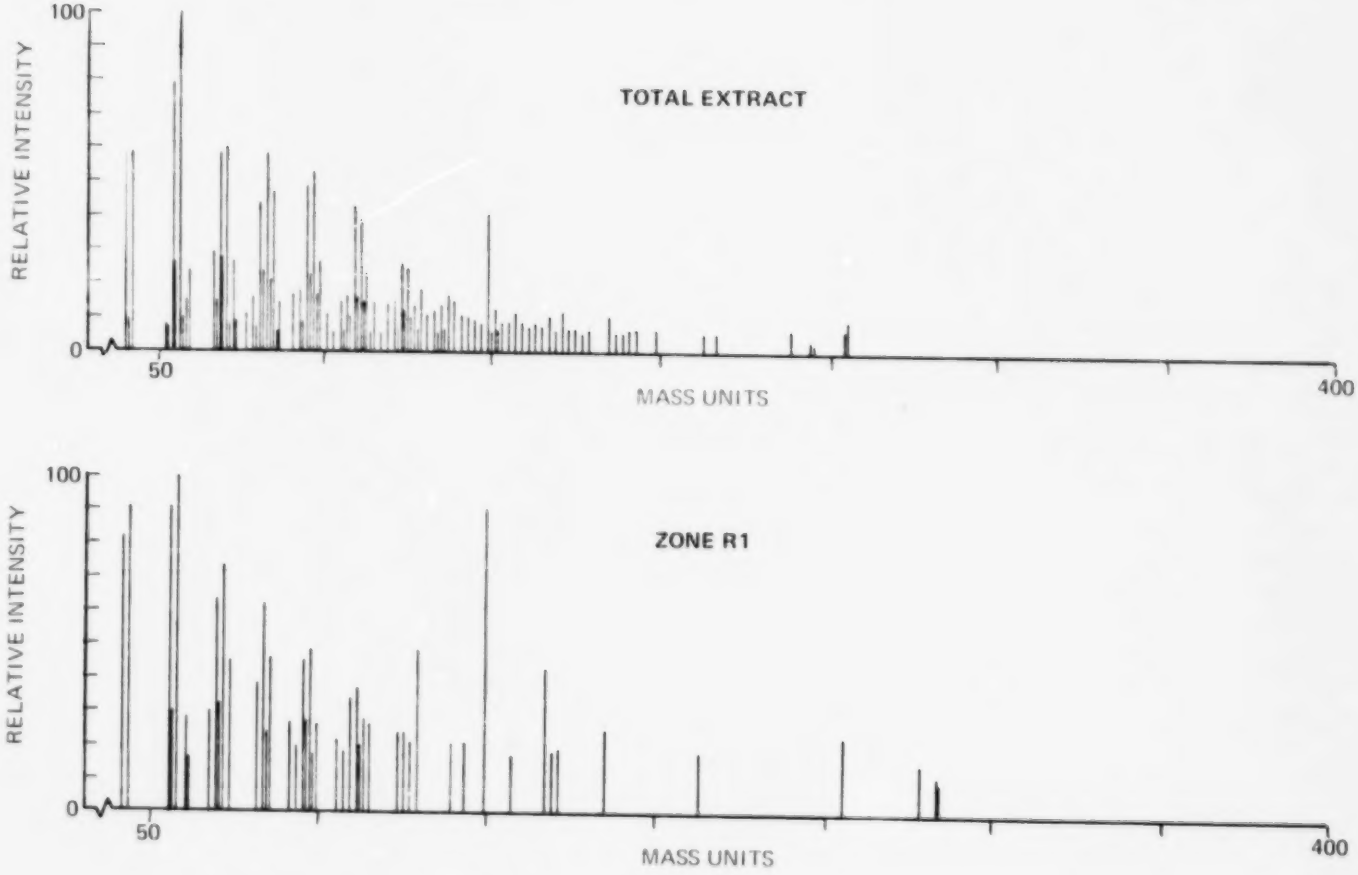


Figure 14. Normalized bar graphs of mass spectra obtained from diethylether/n-heptane TLC separations of chloroform extract of K59 (7-25-74)—total extract and zone R1

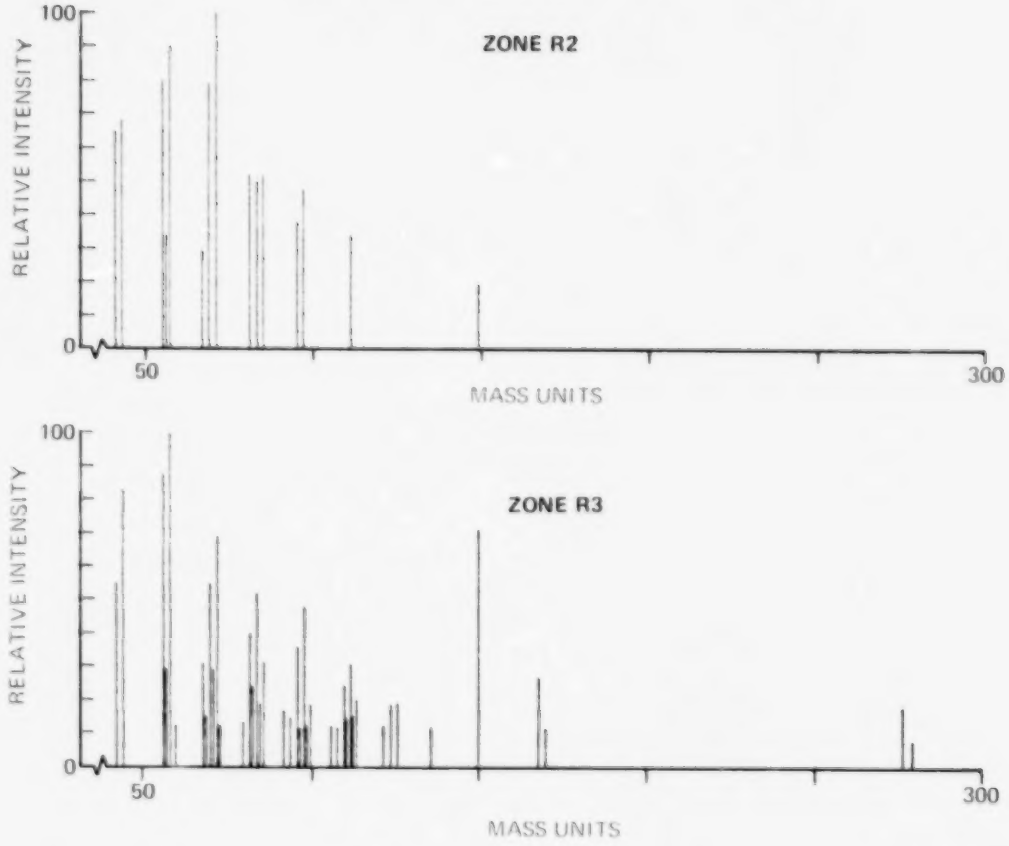


Figure 15. Normalized bar graphs of mass spectra obtained from diethylether/n heptane TLC separations of chloroform extract of K59 (7-25-74)—zones R2 and R3

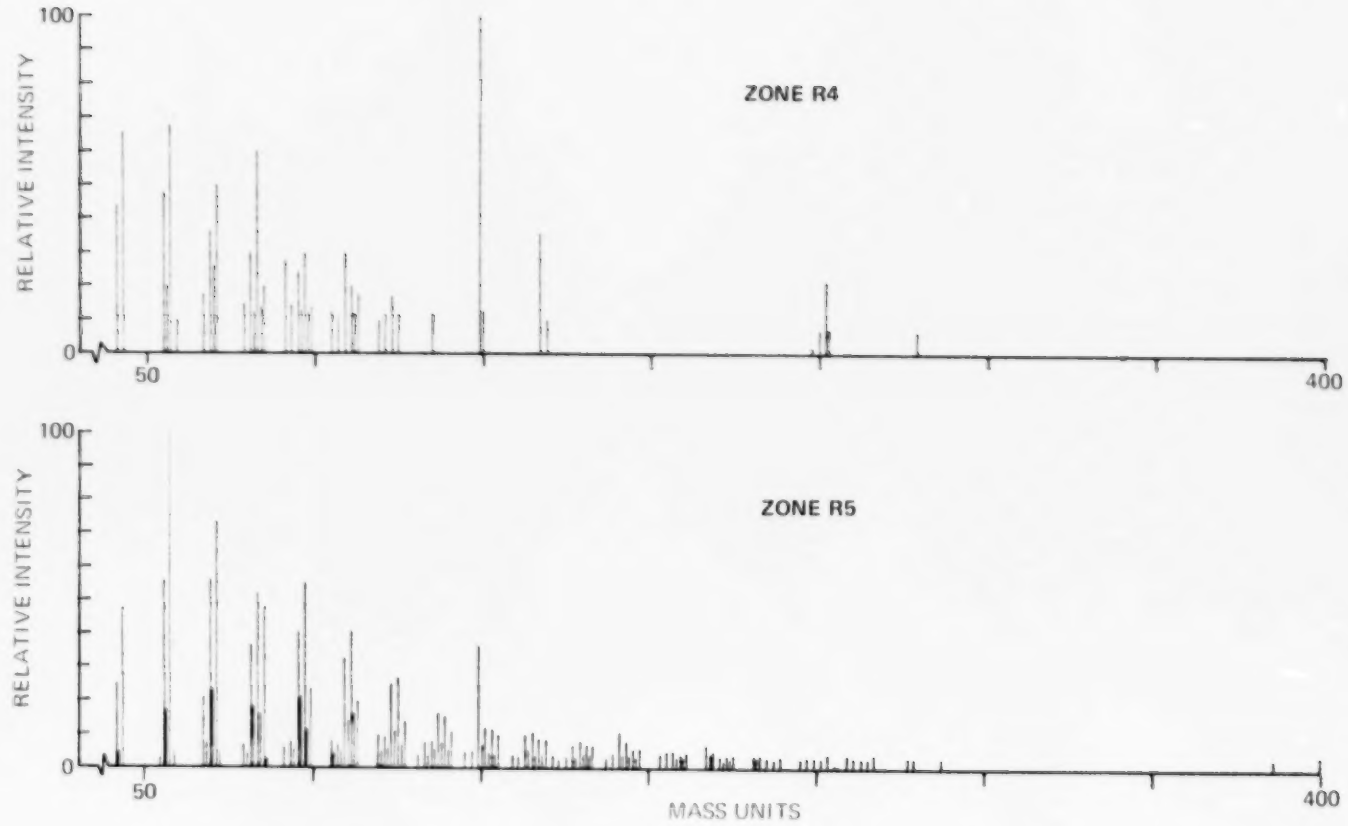


Figure 16. Normalized bar graphs of mass spectra obtained from diethylether/n-heptane TLC separations of chloroform extract of K59 (7-25-74)—zones R4 and R5

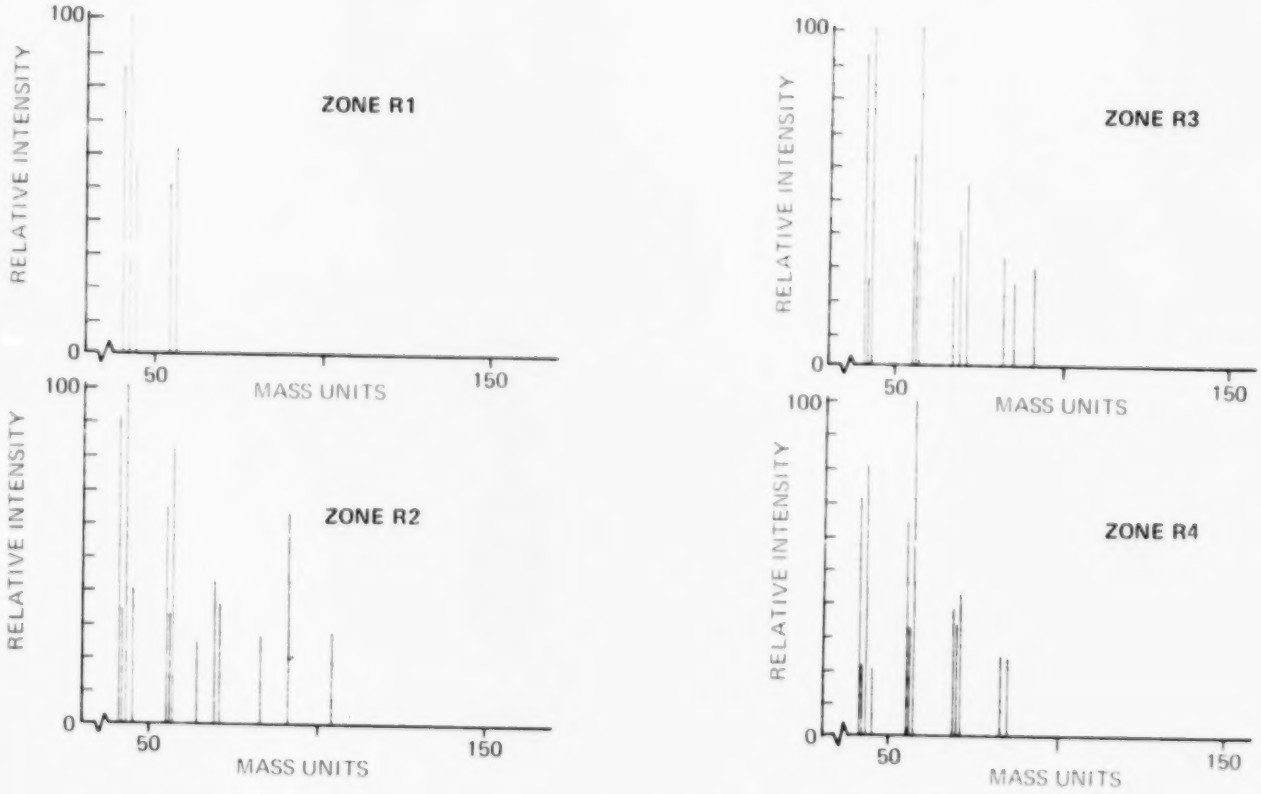


Figure 17. Normalized bar graphs of mass spectra obtained from diethylether/n-heptane TLC separations of chloroform extract of gasoline engine exhaust

Table 12. PRECISE MASS VALUES AND ELEMENT LIST FOR TLC ZONES OF K59 (7-25-74)

TLC,[a] zone	M_{meas}, mass units	Empirical formula	M_{calc}, mass units	$M \times 10^3$,[b] mass units
R1	129.0892	$C_3H_9N_6$	129.0889	0.3
		$C_5H_{11}N_3O$	129.0902	1.0
		$C_7H_{13}O_2$	129.0915	2.3
	149.0248	$C_8H_5O_3$	149.0239	0.9
	167.0345	$C_8H_7O_4$	167.0344	0.1
R2	No peaks intense enough for measurement			
R3	276.0970	$C_8H_{14}N_5O_6$	276.0944	2.6
		$C_{13}H_{14}N_3O_4$	276.0984	1.4
		$C_{11}H_{12}N_6O_3$	276.0971	0.1
		$C_{15}H_{16}O_5$	276.0998	2.8
		$C_{22}H_{12}$	276.0939	3.1
R4	252.0976	$C_9H_{12}N_6O_3$	252.0971	0.5
		$C_{11}H_{14}N_3O_4$	252.0984	0.8
		$C_{13}H_{16}O_5$	252.0998	2.2
		$C_{20}H_{12}$	252.0939	3.7
	253.0963	$C_{10}H_{13}N_4O_4$	253.0937	2.6
		$C_{12}H_{15}N_5O$	253.0950	1.3
		$C_{13}H_{11}N_5O$	253.0964	0.1
		$C_{15}H_{13}N_2O_2$	253.0977	1.4
		$C_{19}C_{13}H_{12}$*	253.0973	1.0

[a]Zones are numbered R1 to R5 with R1 nearest to the origin and R5 taken from the solvent front

[b]Absolute value of the difference between M_{meas} and M_{calc}

*C_{13} Isotope of carbon

Table 12 (concluded). PRECISE MASS VALUES AND ELEMENT LIST FOR TLC ZONES OF K59 (7-25-74)

TLC,[a] zone	M_{meas}, mass units	Empirical formula	M_{calc}, mass units	$M \times 10^3$,[b] mass units
R5	149.0248	$C_8H_5O_3$	149.0239	0.9
	149.1349	$C_{11}H_{17}$	149.1330	1.9
	255.2126	$C_{19}H_{27}$	255.2113	1.3
	255.9928	–	–	–
	256.2172	$C_{14}H_{28}N_2O_2$	256.2151	2.1
		$C_{19}H_{28}$	256.2191	1.9
	279.1640	$C_{10}H_{23}N_4O_5$	279.1668	2.8
		$C_{17}H_{19}N_4$	279.1610	3.0
		$C_{19}H_{21}NO$	279.1623	1.7
	386.3897	$C_{23}H_{50}N_2O_2$	386.3872	2.5
		$C_{28}H_{50}$	386.3912	1.5
	400.4072	$C_{24}H_{52}N_2O_2$	400.4029	4.3
		$C_{29}H_{52}$	400.4069	0.3

[a]Zones are numbered R1 to R5 with R1 nearest to the origin and R5 taken from the solvent front

[b]Absolute value of the difference between M_{meas} and M_{calc}

the ambient air samples indicate that the major contributor to the chloroform extract is gasoline engine exhaust.

The low resolution mass spectra of the five zones obtained by TLC separation of K59 (7-25-74), chloroform extract, were dominated by peaks typical of hydrocarbons. These peaks obscure features of spectra of other organic compounds that may have been chromatographically separated. Thus positive identification of additional compounds in ambient air samples was not furthered by TLC separation due to the small quantity of material available for analysis.

The TLC separation spectra from the gasoline engine exhaust were very weak and show the peaks expected from hydrocarbons, with the exception of peaks at 149 and 167.

Some features of mass spectra are more readily interpreted when combined with precise mass measurements of the peaks, using the peak matching technique. If the mass of an ion can be determined with a precision of ±2 millimass units or better, the combination of elements in its empirical formula can be reduced to a few possibilities or sometimes a single possibility. Tables[19] consulted for actual compound identification were restricted to the four most common elements found in organic compounds: C, H, N, and O. Furthermore, the possible formulae were limited to a minimum of one carbon and a maximum of six each of nitrogen and oxygen.

A peak at 149 appeared in every chloroform extract, but with varying intensity. The 149 peak is usually the largest peak in phthalic acid esters. Precise mass measurements confirm that this ion is $C_8H_5O_3^+$, and is very likely a fragment of alkyl phthalates or phthalic acid. A 167 peak, $C_8H_7O_4^+$, is sometimes observed along with 149 in phthalates and was found in a few of the extracts. This group of esters is widely used as a plasticizer in many common plastic materials such as vinyl chloride, etc.

The gasoline engine exhaust chloroform extract spectrum exhibits peaks at 276, 300 and 326; precise mass measurements indicate that these are probably $C_{22}H_{12}$, $C_{24}H_{12}$, and $C_{26}H_{14}$, respectively. (See fig. 18 for possible isomers corresponding to these formulae.) These all correspond to well known members of the polyaromatic hydrocarbons, and have been detected previously in engine exhausts and air pollution studies.[19] The chloroform extracts of K59, K60, K61, and K99 (all from 7-25-74) had peaks at mass 284. The precise mass values gave $C_{18}H_{36}O_2^+$ as one possible formula. Stearic acid is a very likely possibility whose spectrum has a prominent peak at this mass. Stearic acid and its esters are used in rubber compounding and could be extracted from rubber particles on the filter or deposited directly from the air.

The mass spectra of the chloroform and xylene extracts of K99 (8-21-74) indicate the presence of aliphatic hydrocarbons (alkanes and alkenes) in the chloroform extract and highly unsaturated polyaromatic hydrocarbon compounds in the xylene extract. This was verified by precise mass measurements and infrared spectroscopy.

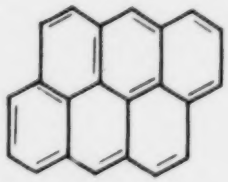
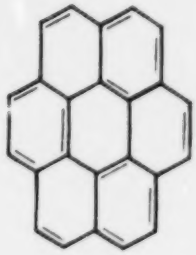
MASS PEAK	POSSIBLE ISOMER AND CHEMICAL FORMULA
276	 $C_{22}H_{12}$
300	 $C_{24}H_{12}$ (CORONENE)
326	$C_{26}H_{14}$

Figure 18. Possible organic compounds found in the chloroform extract of gasoline engine exhaust

ELEMENTAL ANALYSIS

The results of the ambient air test specimens that were analyzed for elemental composition by energy dispersive X-rays show large variations (±200% of the amount present) for individual elements and specimens. However, the effect of these variations appears to be minimized when treated statistically.

The EDX results of the source test specimens are listed in table 13. Several elements were found in the sources with many elements common from source to source. The road dust samples appear to be contaminated by local sources.

OPTICAL ANALYSIS

Particle Size Distribution

Forty-seven membrane filter samples from ambient air testing were examined to determine their particle size distribution. At least six samples from each site were included with all sites represented for August 3, 1974 and August 21, 1974. Table 14 lists the (arithmetic) average particle size distribution; the sites are arranged from north (K60) to south (K59). This table indicates a homogeneous particle size distribution in the Duwamish Basin with a slight trend toward decreasing size from north to south.

Density Separation

Density gradient columns were prepared for all filters. The mean densities of collected particulate are illustrated in figure 19 for 22 sampling intervals. The general trend is for mean density of particulate to decrease from north to south with K60 having the heaviest particles. The mean density of K60 is lower for weekends and holidays than for weekdays; this implies that a source of heavy particulate is located north of K60 (meteorological data) and emits pollution at a higher rate on workdays than on nonworkdays. The area north of K64 appears to contain another source for heavy particulate if the average wind conditions of the Basin are indeed applicable to K64.

Particulate Identification—Characterization

The results of the semiquantitative optical analysis of eleven ambient air test samples are listed in table 15 according to the restrictions and particle class criteria described in table 4. The five samples taken on 10-16-74 were examined to determine the effect of an air stagnation alert. The other samples were chosen on the basis of density separation data as being representative collections of particulate for each site. The last three rows of table 15 represent probable particulate origins; some of the particle classes cannot be strictly attributed to one type of origin; in these cases the values are distributed among the probable origins as described below.

Particles having a probable natural origin include those attributable to wind erosion of exposed surfaces, open burning of biological materials, pollination, etc.

Table 13. ANALYSIS OF SOURCE TESTS

Source test	Elements detected by EDX[a]		
	Major	Minor	Trace
Gypsum–ship conveyor belt	S, Ca, Sr	K	Al, Fe, Mn, Cu, Br
Harbor Island road dust	Si, Fe, Ca	Al, K, Pb, S	Ti, Cl, Mn, Zn, Sr, Cu, Zr, As, Ni, V
Gasoline engine exhaust	Pb, Fe	Br, S	Cl, Ca, As, Zn, Al, K, V, Ti
Diesel switch engine exhaust	S, Cl, Si, Ca	Fe, Al, K	Zn, Cu, Ti, Pb, Mn, Ni, Sr, Zr, V
Flour Mill			
5-mill cyclone	S, Cl	K, Ca, Fe	Zn, Cu, Ni, Zr, Ti, V, As, Nb
Baghouse	S, Cl	Ca, Fe, K	Zn, Sr, Pb, Al, V, As, Zr, Ti
Steel plant			
High-temperature baghouse	Fe, Zn	S, Pb	Mn, Ca, K, Cu, Cl, Ni, Br, V, Ti, Nb
Diesel truck exhaust	Cl, S	Ca, Fe, Zn	Cu, Mn, K, V, Zr, Ti
Diesel oil boiler	S	Fe	Zn, Sr, Zr, V, Ti, K, Pb
Road dust (Port of Seattle)	Fe, Si, Ca	Al, K	S, Ti, Mn, Sr, Zn, Pb, Cu, As, Zr, V, Mo
Battery processor fugitive emissions	Si, Cl, Sb	S, Pb	Al, Fe, As, Ti, Cu, Zn, Sr, K, Mo
Cement plant fugitive emissions	Ca, Fe	Al, Si, S, Cu, Zn, Pb, Sr	K, Ti, Mn, As

[a]Elements analyzed by EDX: Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Br, Sr, Zn, Nb, Mo and Pb.

Table 14. PARTICLE SIZE DISTRIBUTION BY SITE
(average % by particle count)

Site	0.5-3 microns	3-7 microns	Over 7 microns
K-60	66	27	7
K-55	69	24	7
K-99	68	23	9
K-61	72	21	8
K-64	71	21	8
K-59	75	19	6

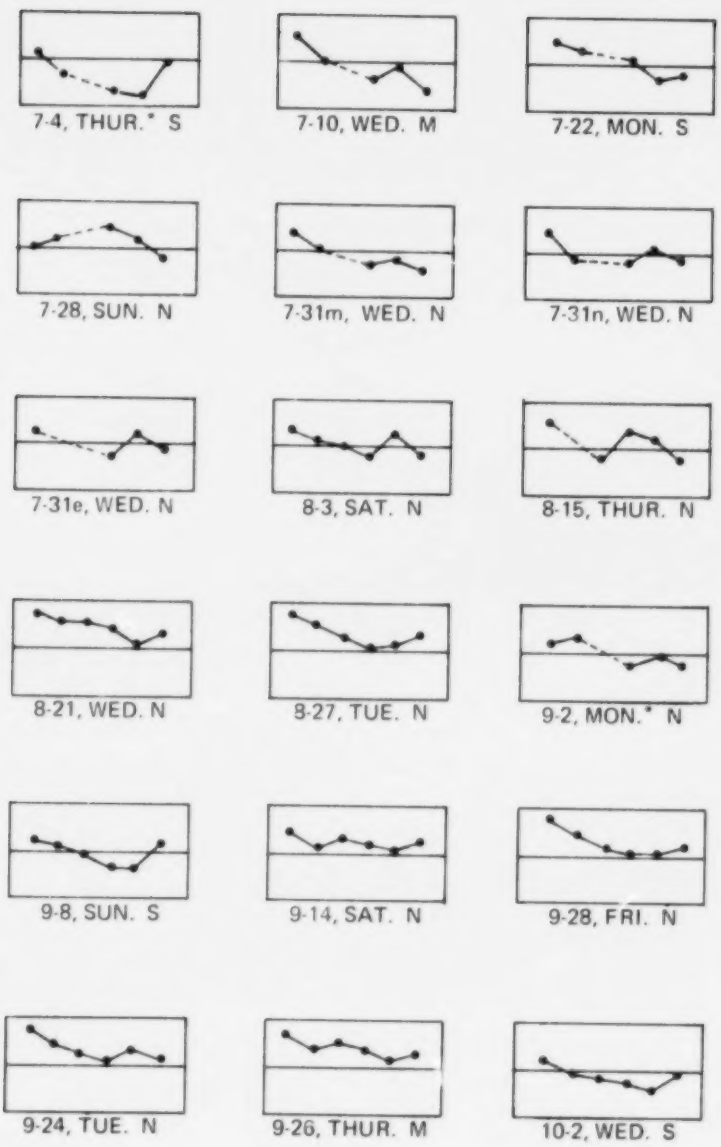


Figure 19. Mean densities of samples by site

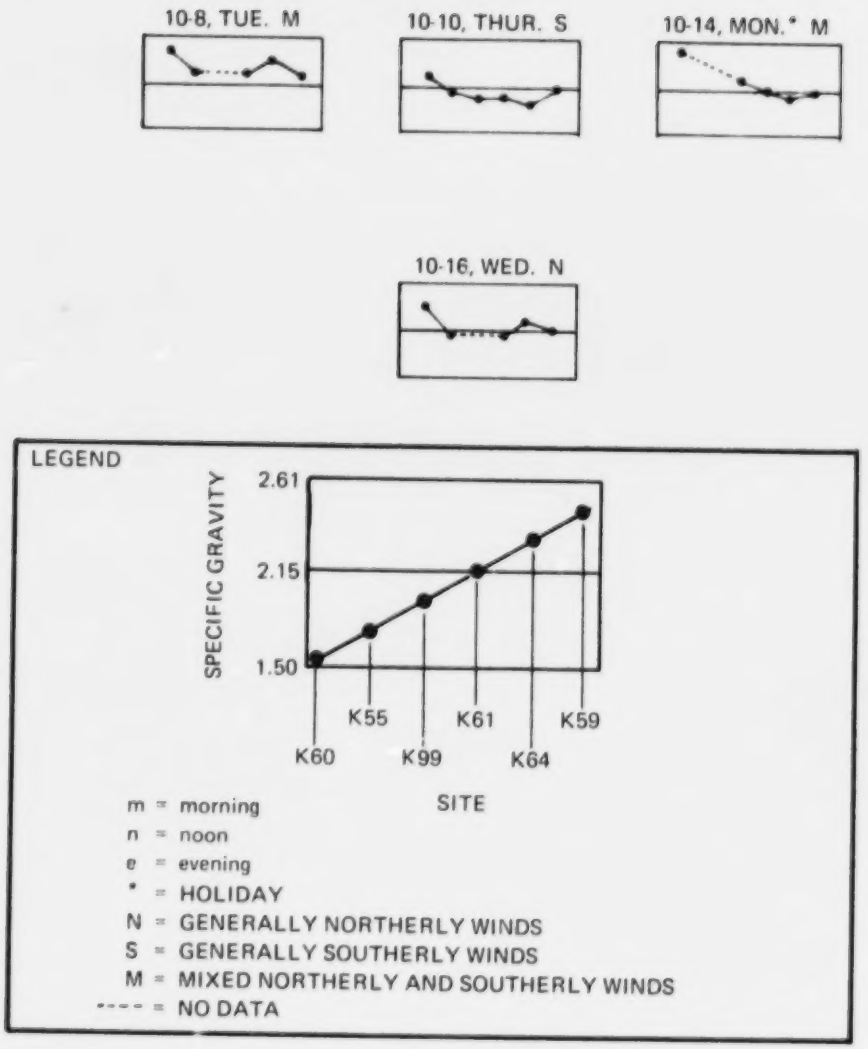


Figure 19 (concluded). Mean densities of samples by site

Table 15. SEMIQUANTITATIVE PARTICULATE CLASSIFICATION BY SITE
(% by weight)

Particle class	Site and date sampled										
	K-60		K-55		K-99	K-61		K-64		K-59	
	(7-13)	(10-16)	(8-15)	(10-16)	(8-27)	(7-10)	(10-16)	(8-3)	(10-16)	(7-31)	(10-16)
1 Pollens and spores	5	10	13	10	12	20	10	20	8	13	10
2 Starch	2	2	10	1	5	1	4	1	2	2	1
3 Plant parts	1	4	5	4	7	2	5	5	5	7	10
4 Furnace slags	10	7	3	1	1	1	1	2	1	2	2
5 Furnace spheres	15	20	16	15	5	2	12	3	18	5	8
6 Furnace ash	8	8	5	5	5	3	8	2	8	4	5
7 Fly ash	8	5	2	2	5	3	2	5	2	5	2
8 Abrasive dusts	1	1	1	1	1	1	1	1	1	1	1
9 Concrete minerals	3	5	2	8	2	1	8	6	10	1	8
10 Road dust minerals	36	20	30	30	35	45	40	40	32	35	35
11 Soot	5	15	6	20	12	13	15	8	10	12	12
12 Tire rubber	1	1	2	2	1	4	2	3	1	5	2
13 Other	5	2	5	2	10	5	2	5	3	8	5
Probable origin[a]											
Natural	10	22	26	24	26	42	21	45	19	31	30
Transportation	45	30	27	44	41	45	39	36	37	44	41
Industry	45	47	47	31	33	11	39	18	44	25	28

[a] The sum of these values is 98-100% because classes representing 1% were not distributed. See text for method of determining these values.

$$\% \text{ natural origin} = (\% \text{ pollen and spores}) + (\% \text{ wind attributed road dust}) + (\% \text{ plant parts} - \% \text{ starch})$$

Because the aerolian effects that carry the pollen also lift and carry fine exposed minerals, the percentage of road dust minerals attributed to wind erosion is arbitrarily set equal to the pollen percentage. This is a simplification, but if the road minerals were excluded or added in their totality, a much more biased value would result. A similar logic applies to class 3 (plant parts). Many of the plant parts found were wheat related and should therefore be included with the industrial group of particles. If the "% plant parts minus % starch" value was less than 1%, it was assigned the value "0."

Particles having a probable transportation-related origin include those emitted and entrained by moving vehicles.

$$\% \text{ transportation origin} = (\% \text{ road dust} - \% \text{ pollen}) + (\% \text{ fly ash}) + (\% \text{ soot}) + (\% \text{ tire rubber})$$

The reduced road mineral value represents that which as a minimum could be attributed to transportation-related dust. Fly ash is included in this group because of its restricted definition. (Normally the term fly ash would include the three classifications of fly ash, furnace ash, and furnace spheres.) The distinction in this study was made on the basis of standards available for the Duwamish Basin. Fly ash is restricted to bulbous, yellow-orange, large particulate; this type of material was not found in any of the industrial furnace source samples, but was seen in some of the oil boiler and diesel engine samples. More source samples must be evaluated before attributing this material to a specific source, but whatever the source, the size of the particulate implies a lack of filtering following the materials' production; therefore the most probable cause of this material is shipping and transportation. The contribution from stationary boilers was not considered because most stationary boilers in the Duwamish Basin burn natural gas during the summer.

Soot is restricted in this study to refer to oil soot. The source of oil soot is, by the same argument, predominantly the result of transportation-related activities. Some interference would be expected with furnace spheres due to the similar optical and density characteristics of some of the furnace spheres. Tire rubber has optical characteristics similar to some of the furnace ash, but the extent of misrepresentation is probably small because of the accessory formations present on the more brittle black furnace ash.

Particles having a probable industrial origin include those attributable to stack emissions, construction, etc.

$$\% \text{ industrial products} = (\% \text{ furnace slag}) + (\% \text{ abrasive dusts}) + (\% \text{ furnace ash}) + (\% \text{ furnace spheres}) + (\% \text{ starch}) + (\% \text{ plant parts, corrected}) + (\% \text{ concrete minerals}) + (\% \text{ other})$$

The % plant parts was included at the starch percentage value because of the relationship between chaf, wheat tissue, and wheat trichomes that were usually found in association with

the starch. The classification of "other" as used in this study includes a wide range of particle types, the majority of which are of an industrial nature.

Furnace slags were found in this study to be of two different types that are characteristic of different types of furnace operations. The first (platy and brownish) is typical of rotary kilns during normal operation; fines liquified by a brief exposure to the flame impact on the kiln walls, cool and flake off into the exhaust stream. The second type of slag (striated and colorful) is typical of furnace operations where slag is tapped off the furnace into pots to cool; striation occurs during cooling. The color variation is the result of different metallic ions and compositions of the slags. This second type of slag is often used to cover parking lots, as aggregates in asphalt and concrete, or as land fill. Its presence in the air sample indicates that it is airborne as construction material, erosion product, or wind-blown refuse from the slag dump yard of an industry using this type of furnace, and not as a stack emission from a furnace. It should be mentioned that this type of slag is often used by the cement industry as a source of iron in their production of cement and may become airborne during that operation.

Concrete minerals cover a wide variety of particle types. Cement cinders are the easiest identified. These cinders can give an indication of the types of cement being produced and idiosyncrasies of the individual plant operations. Of the eleven air samples optically evaluated, only two did not contain cement cinders in a detectable concentration, K60 (7-13-74) and K59 (7-31-74). The majority of particles counted in this classification were of the hydrated cement type. Standards for comparison of this very complex group were collected from actual Duwamish Basin cement industries and from hydrated samples of other commercially available cements. These hydrated compounds may result from cement plant emissions contracting water vapor in the atmosphere, the construction or destruction of concrete buildings or roads, etc. There are references in the literature to the quantity and composition of hydrated cement forms emanating from the cement industry,[13] but the quantity resulting from construction is not well documented because of the difficulty presented in monitoring such an operation.

In some of the samples, metal turnings amounted to as much as 1% and more of the total sample. This level of metal turnings implies a high level of other types of metal working particulate. Welding, power grinding and metal torch cutting result in large amounts of particles in the furnace ash and/or furnace sphere group. Foundries, metal machining industries, and general steel construction probably contribute to the furnace ash, furnace sphere and furnace slag classifications. The amount of metal turnings in a sample may be an index to the amount of furnace spheres and ash attributable to metal working as opposed to metal production.

Table 15 clearly shows that natural minerals contribute from 10-45 wt % of the total particulate. These minerals may originate from wind erosion, vehicle movement on dirt or gravel roads, or construction involving the use of dried aggregates. Concrete minerals are found throughout the Basin, though cement cinders are not present in detectable concentrations in every sample. Oil soot is also a large contributor.

An average of 30% of the total particulate loading originates from natural sources when considering representative ("normal") samples. Those samples taken during the air

stagnation alert show an average of 23% for natural particulate with a corresponding increase in particulate attributable to transportation and industry. Additionally, the stagnant air samples showed a more uniform distribution of particulate among the sites and particle classes than the representative samples; this implies quite a bit of atmospheric mixing at low elevations including re-entrainment of particulate.

SCANNING ELECTRON MICROSCOPE ANALYSIS

Scanning electron microscope secondary electron images of airborne particulate are displayed in figure 20. Most of these particulate were found to be submicron versions of or fragments of similar particulate observed in the optical analysis. It was of particular interest, however, to see at 10,000X that there are many extremely small particulate (<0.1) contained in the ambient samples.

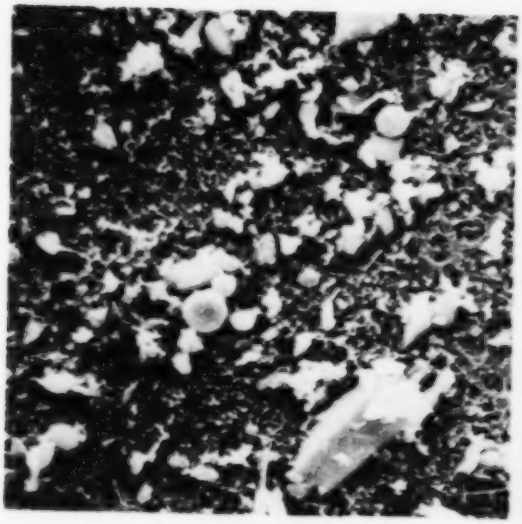
X-RAY DIFFRACTION ANALYSIS

The X-ray diffraction results from source and ambient samples are listed in table 16. The predominant compounds identified were Fe_3O_4, SiO_2 and feldspars in the ambient air test specimens. The attempt to segregate these compounds out by density was not successful due to the nature of the particulate, i.e., some high density material occurs as fine coating on thin-shelled glass bubbles (observed optically).

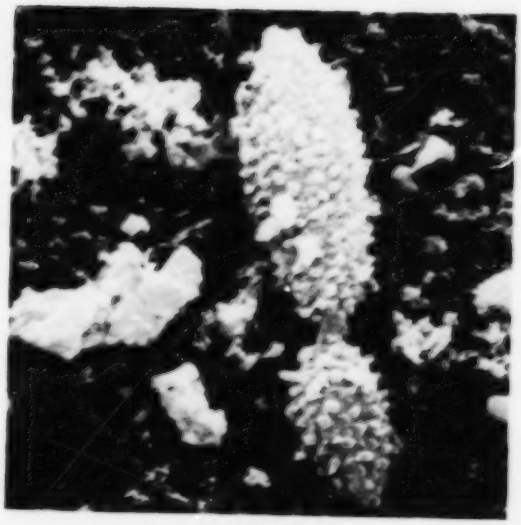
COMPUTER ANALYSIS

Results from the statistical analysis by computer appear to be valid only when a minimum of 50 data sets is available for analysis. Data sets include results from gravimetric, meteorological, and elemental analyses; the number available for statistical analysis being limited by the number of specimens analyzed for elemental composition. The last sampling date analyzed by EDX was September 26, 1974, so a total of 110 samples (75 north, 35 south and mixed wind conditions) was available for statistical analysis.

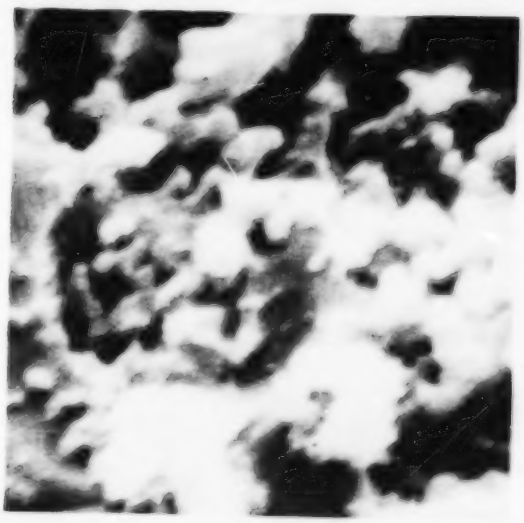
The General Linear Hypothesis program, BMDX64, relates the independence of each linear term of the model (μ_i, α_i, a_k) with respect to the dependent variable. The calculated values of the F-random variable,[20] with appropriate degrees of freedom, provide a test of the independence or interrelationship of meteorological variables and site locations. Table 17 lists these values of F calculated using the 75 data sets (samples) associated with northerly winds and based on concentration of variable per cubic meter of air. There is 95% confidence ($F > 3.97$) that there is some minimum amount of ashable organics present in the atmosphere at all times. There is a 90% confidence ($F > 2.77$) that TSP, PC and Cu are present at all times. It may be stated with 95% confidence that the following variables are affected by geographic location of the samples: TSP, PC, Ca, Mn, Fe, Zn, Pb, and Zr; while Al, Si and K (90% confidence) also seem to be related to site location. Wind speed affects the amount of ashable organics, Si, S, Cl, V (95% confidence), K, Zn, and As (90% confidence). The intensity of the inversion affects the largest number of variables.



A. 1,000X



B. 5,000X



C. 20,000X

Figure 20. Representative SEM photographs (K60, 8-21-74)

Table 16. X-RAY DIFFRACTION ANALYSIS OF AIR AND SOURCE TESTS

Specimen	Inorganic compounds detected
K60 (7-25-74)	Fe_3O_4, SiO_2, feldspars
K60 (8-21-74)	Fe_3O_4, SiO_2, feldspars, Al_2O_3
K59 (7-25-74)	Fe_3O_4
K59 (8-21-74)	Fe_3O_4, SiO_2, feldspars
Harbor Island road dust	SiO_2, feldspars
Road dust (Port of Seattle)	SiO_2, feldspars
Gypsum plant	$CaSO_4\ 2H_2O$
Battery processor baghouse	$PbSO_4$, $PbCl_2$
Cement plant	
Cooling tower	$CaCO_3$, SiO_2
Electrostatic precipitator	Alite
Baghouse emission	$CaCO_3$, $CaSO_4\ 2H_2O$ and ?($CdPbO_5$, $K_3Na(SO_4)_2$, $Ba_3MgSi_2O_8$, SiO_2)?
Steel plant, high-temperature baghouse	Fe_3O_4, ?(SiO_2)?

Table 17. STATISTICAL F VALUES CALCULATED FROM 75 NORTHERLY WIND SAMPLES (if F > 3.97 then 95% confidence; if F > 2.77 then 90% confidence for all columns except α)

Dependent variable	μ	α	WS	II	ID	LR	AQ
TSP	3.31	8.52	1.16	31.14	0.20	0.02	0.98
PC	3.16	6.90	1.35	32.38	0.32	0.08	1.25
AO	4.26	1.56	10.40	54.52	0.17	0.11	0.64
Al	1.01	2.12	1.70	1.39	0.13	0.06	0.04
Si	0.70	1.97	4.21	1.55	1.47	0.33	0.13
S	1.63	1.48	4.50	0.10	0.36	0.13	0.24
Cl	0.96	1.18	5.51	0.25	3.68	0.61	2.03
K	0.98	2.02	3.76	1.58	0.58	0.03	0.16
Ca	0.08	3.43	0.27	0.91	1.12	1.05	1.00
Ti	1.40	1.68	0.63	3.96	0.48	0.13	0.001
V	1.66	1.46	12.85	1.12	0.95	2.24	1.02
Cr	0.30	0.37	0.30	16.73	2.38	0.56	0.77
Mn	2.08	13.54	0.39	13.61	0.74	0	0.66
Fe	0.03	10.95	0.33	16.60	0.81	0.66	1.66
Ni	1.09	0.79	0.08	5.99	1.53	0.40	0.14
Cu	3.18	0.68	0.62	5.61	0.87	0.32	0.90
Zn	0.96	10.92	2.95	18.74	0.27	0.08	1.33
Br	0.10	1.79	0	7.44	1.92	0.06	0.43
Pb	0.73	3.39	1.87	8.97	0.86	0.82	0
Sr	0.45	0.97	0	2.31	1.07	7.88	2.67
Zr	0.08	3.50	0.39	17.97	4.69	2.20	0.03
Nb	0.01	0.21	0.12	1.96	0	1.43	1.18
Mo	0.35	0.60	0.01	0.34	1.54	0	0.27
As	0.42	1.36	3.08	6.44	1.38	0.01	0.75

Explanation of symbols and abbreviations

- μ = minimum amount of dependent variable present in atmosphere at all times
- α = site contribution to amount of dependent variable; 95% confidence if F > 2.34 and 90% confidence if F > 1.93
- WS = wind speed
- II = intensity of inversion
- ID = duration of inversion
- LR = time since last rain
- AQ = soiling index as measured by tape sampler at K55
- TSP = total suspended particulate normalized to a 24-hr period
- PC = particulate concentration
- AO = ashable organics

BMDX64 also calculates the concentration for each dependent variable by site. These values are listed in table 18 and illustrated in appendix A, because the visualizations are quite helpful for interpreting the results of both computer programs.

The Stepwise Regression program, BMD02R, calculates the effect of the dependent variables on the variation of PC and a symmetric correlation matrix for all 30 of the independent and dependent variables. Table 19 illustrates the percent correlation between each variable: a positive value indicates that the quantities influence each other in such a manner that if one quantity increases so does the other; a negative correlation indicates that if one variable increases the other will decrease. Please note the high correlation between normalized TSP and PC; this indicates that a constant rate of flow of air was maintained over the three months of this study for which elemental data are available. Ashable organics and iron account for 90% of the variation of particulate concentration.

Table 18. AVERAGE CONCENTRATION OF VARIABLES BY SITE
($\mu g/m^3$ except TSP, mg)

Variable	Site					
	K60	K55	K99	K61	K64	K59
TSP[a]	218.292	151.578	139.710	115.924	155.662	97.492
PC[b]	145.500	102.500	95.683	77.731	99.407	73.715
AO[c]	24.910	24.462	23.375	19.469	21.673	21.051
Al	0.715	1.030	0.651	0.556	1.222	0.639
Si	3.337	9.423	5.862	10.959	14.556	6.020
S	2.118	7.128	4.659	5.795	7.257	3.136
Cl	2.824	1.768	1.010	3.854	3.640	1.134
K	0.930	1.552	1.256	1.933	2.260	1.009
Ca	4.783	14.064	6.083	7.245	7.519	3.257
Ti	0.381	0.302	0.293	0.256	0.430	0.226
V	0.040	0.055	0.033	0.034	0.036	0.023
Cr	0.062	0.072	0.078	0.651	0.037	0.053
Mn	0.329	0.217	0.132	0.102	0.111	0.113
Fe	14.181	7.860	4.946	3.937	5.131	4.005
Ni	0.033	0.074	0.046	0.045	0.029	0.030
Cu	0.515	0.603	0.456	0.477	0.611	0.606
Zn	1.127	0.580	0.342	0.289	0.318	0.256
Br	0.075	0.041	0.065	0.067	0.113	0.235
Pb	3.936	2.492	1.500	1.656	1.939	2.579
Sr	0.052	0.041	0.107	0.030	0.037	0.037
Zr	0.055	0.033	0.018	0.025	0.028	0.022
Nb	0.145	0.217	0.240	0.156	0.216	0.176
Mo	0.005	0.001	0.003	0	0.005	0
As	0.006	0.005	0.006	0.006	0.001	0.002
No. of readings	(9)	(13)	(12)	(13)	(15)	(13)

[a]TSP = total suspended particulate normalized to a 24-hr sample period, mg

[b]PC = particulate concentration, $\mu g/m^3$

[c]AO = ashable organics, $\mu g/m^3$

Table 19. SYMMETRIC CORRELATION MATRIX CALCULATED FROM 75 NORTHERLY WIND SAMPLES

(Percent correlation)

	WD	WS	TH	TL	IL	IH	II	ID	LR	AQ	TP	PC	AO	Al	Si	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Br	Pb	As
WD	100	25	20	1	27	31	20	32	39	-15	33	33	30	17	13	13	10	12	4	22	14	7	6	13	-10	-16	3	8	20	7
WS		100	12	-20	14	-8	-7	4	2	-8	-10	-11	-25	13	-24	-21	-22	-20	-9	-7	-38	0	-4	-12	-21	-17	-23	-2	-15	1
TH			100	79	0	17	19	19	24	-26	30	31	30	17	10	13	17	21	6	23	12	10	12	16	5	-5	12	18	16	17
TL				100	-2	6	16	14	20	-23	29	30	25	26	28	20	37	32	10	36	18	9	17	23	0	-2	18	19	2	3
IL					100	71	-2	64	66	11	7	7	-3	17	6	5	-7	-4	11	15	-3	-10	9	3	-13	-21	-6	-9	-9	-5
IH						100	40	82	50	-9	23	24	28	28	10	22	4	9	14	21	20	0	9	7	4	-19	8	8	5	-3
II							100	45	13	-25	53	54	71	24	8	14	6	19	17	27	28	49	37	34	34	22	37	34	44	16
ID								100	52	0	26	26	32	19	0	14	-14	3	17	10	17	14	18	13	18	0	12	0	29	15
LR									100	-31	13	14	11	10	9	1	10	6	-6	11	2	8	5	8	4	-5	2	5	8	17
AQ										100	-8	-8	-11	-7	-6	6	-26	-12	13	-12	-10	-17	4	0	-5	6	2	-21	-6	3
TP											100	99	81	36	10	14	22	27	26	54	31	23	67	77	15	25	73	18	52	21
PC												100	84	38	11	16	22	28	27	54	33	26	70	78	17	27	74	21	54	24
AO													100	28	6	14	8	19	16	35	36	35	49	51	26	24	58	36	52	25
Al														100	72	79	58	72	69	82	55	3	22	28	14	22	18	14	13	25
Si															100	84	75	92	64	75	54	-5	-1	10	18	23	3	9	-2	18
S																100	61	82	79	68	73	-4	6	10	32	25	5	4	-2	30
Cl																	100	80	38	62	43	-4	0	21	9	19	14	9	-2	15
K																		100	65	83	55	5	9	23	27	35	17	13	11	24
Ca																			100	60	63	4	31	31	36	31	26	-6	11	27
Ti																				100	46	12	40	49	12	29	35	15	25	24
V																					100	6	27	29	56	36	34	5	27	23
Cr																						100	46	33	28	30	24	5	41	14
Mn																							100	88	32	42	75	2	61	22
Fe																								100	29	44	89	12	68	27
Ni																									100	48	36	3	37	37
Cu																										100	44	16	56	35
Zn																											100	12	68	17
Br																												100	25	10
Pb																													100	26
As																														100

Explanation of table headings:

- WD = wind direction
- WS = wind speed
- TH = ground temperature, high
- TL = ground temperature, low
- IL = inversion base (lower height)
- IH = inversion height
- II = inversion intensity
- ID = inversion duration
- LR = time since last rain
- AQ = COH index as measured by tape sampler at K55
- TP = total suspended particulate normalized to 24 hours
- PC = particulate concentration
- AO = ashable organics
- Al—As are the chemical symbols for the elements found by EDX

SECTION VII

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SECTION VIII

GLOSSARY OF ABBREVIATIONS

COH - Coefficient of haze; an air quality index measured by the amount of light passing through a sample collected on a continuous tape.

DOE - Washington State Department of Ecology.

EDX - Energy dispersive X-ray (analysis); a method of determination of elemental composition through characteristic X-ray fluorescence.

Hi-Vol - High-volume air sampler.

LTA - Low-temperature ashing; a method for determination of the total amount of oxidizable organics.

NA - Numerical aperture.

NBS - National Bureau of Standards.

PC - Particulate concentration, $\mu g/m^3$; gravimetric data.

PSAPCA - Puget Sound Air Pollution Control Agency.

TLC - Thin layer chromatography; a microchemical method for characterization and separation of organic compounds.

TSP or TP - Total suspended particulate, gm or mg; gravimetric data.

μ - Micron.

$\mu g/m^3$ - Gravimetric data.

APPENDIX

Figures 21 through 35 are helpful in visualizing the extent of correlation between variables and the variation of chemical elements by geographic location. These figures represent arithmetic averages for 75 samples from days having predominantly northerly winds.

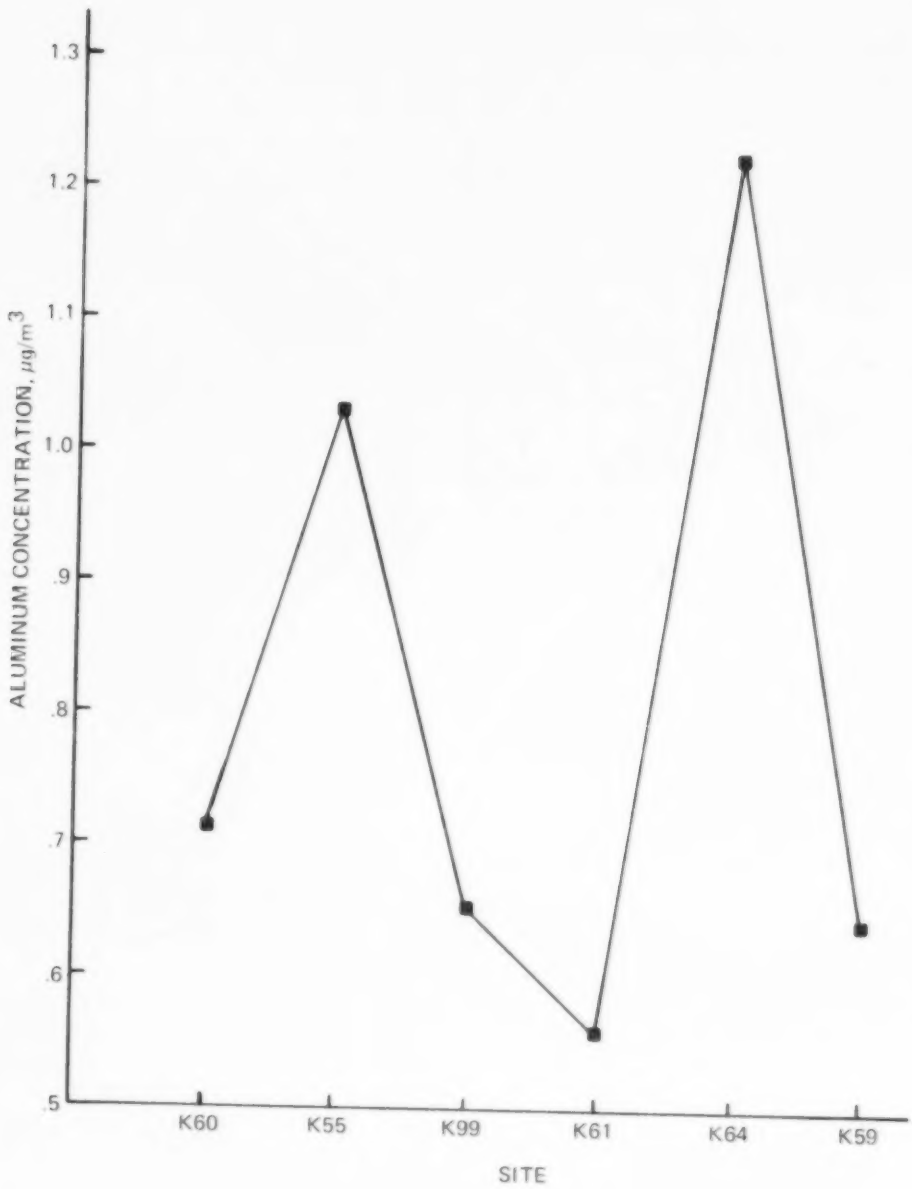

Figure 21. Average concentration of aluminum by site (northerly winds)

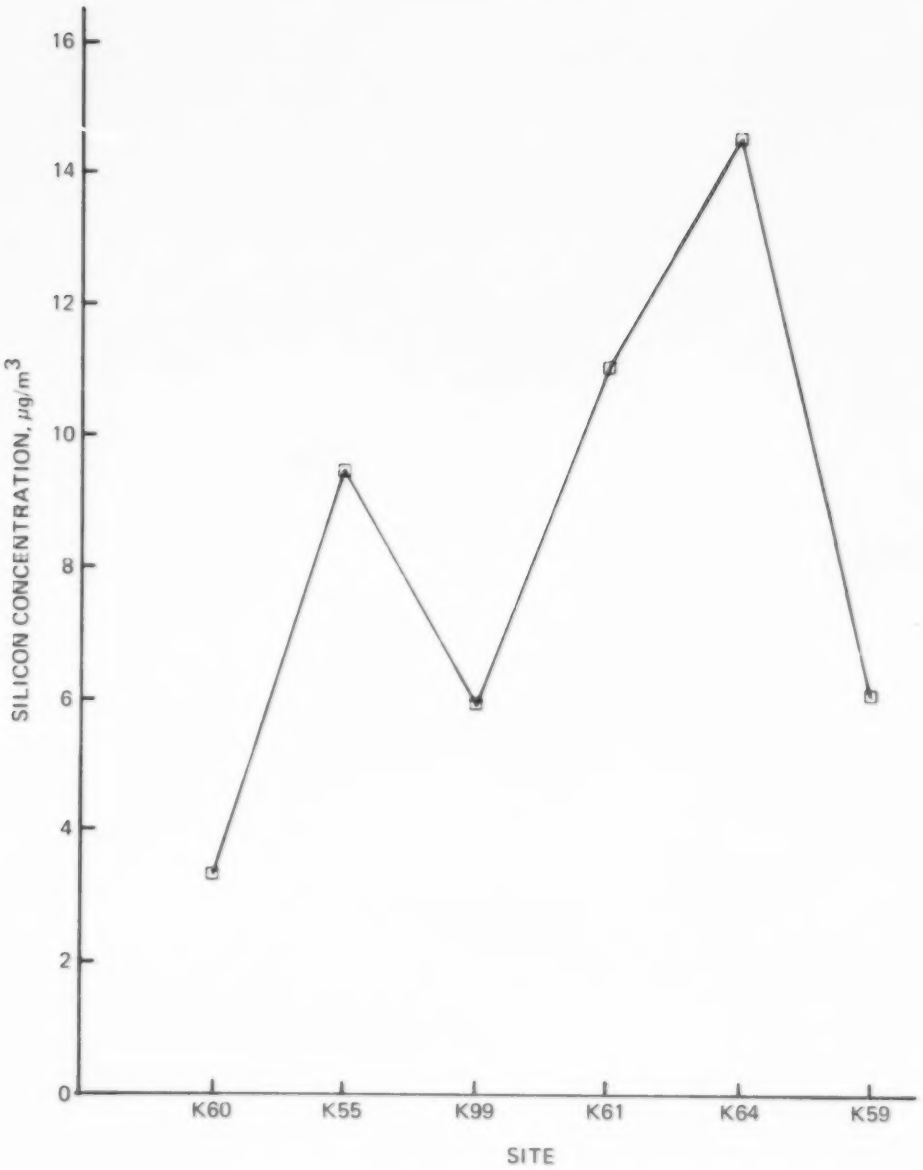

Figure 22. Average concentration of silicon by site (northerly winds)

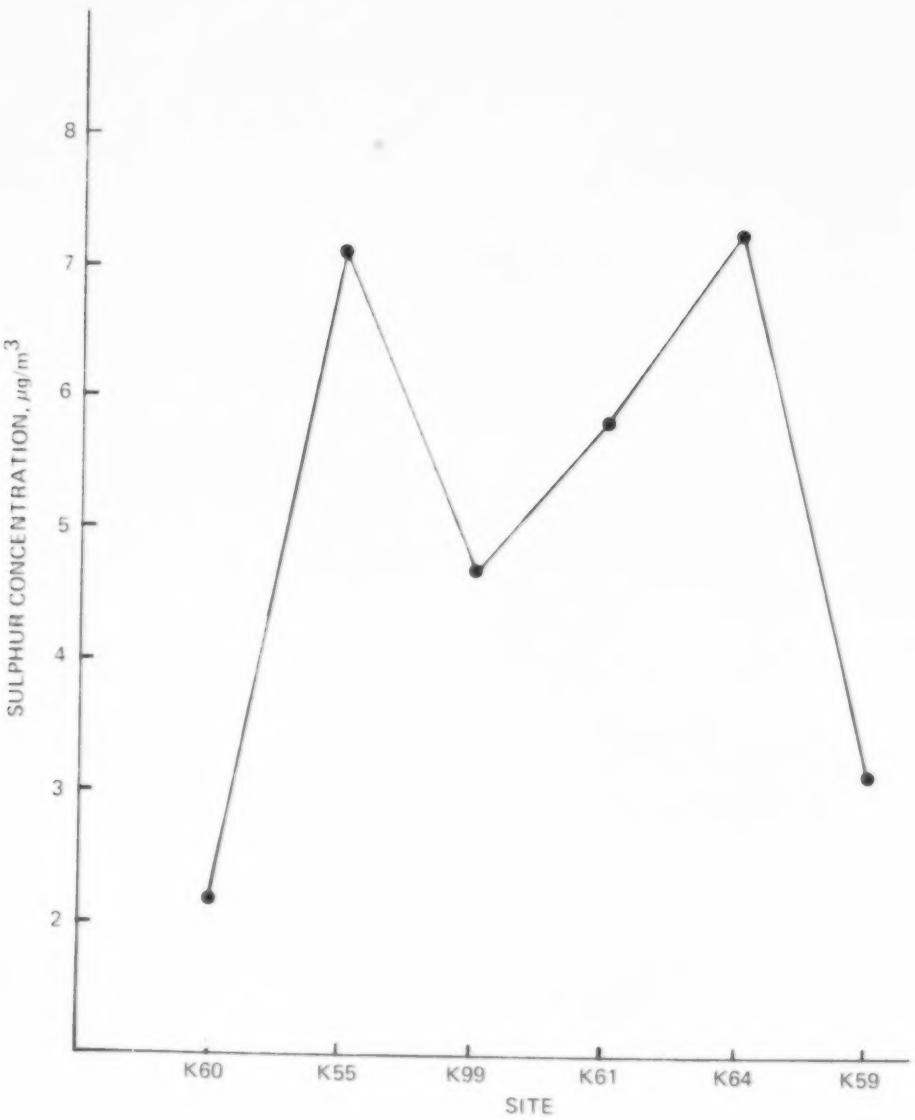

Figure 23. Average concentration of sulphur by site (northerly winds)

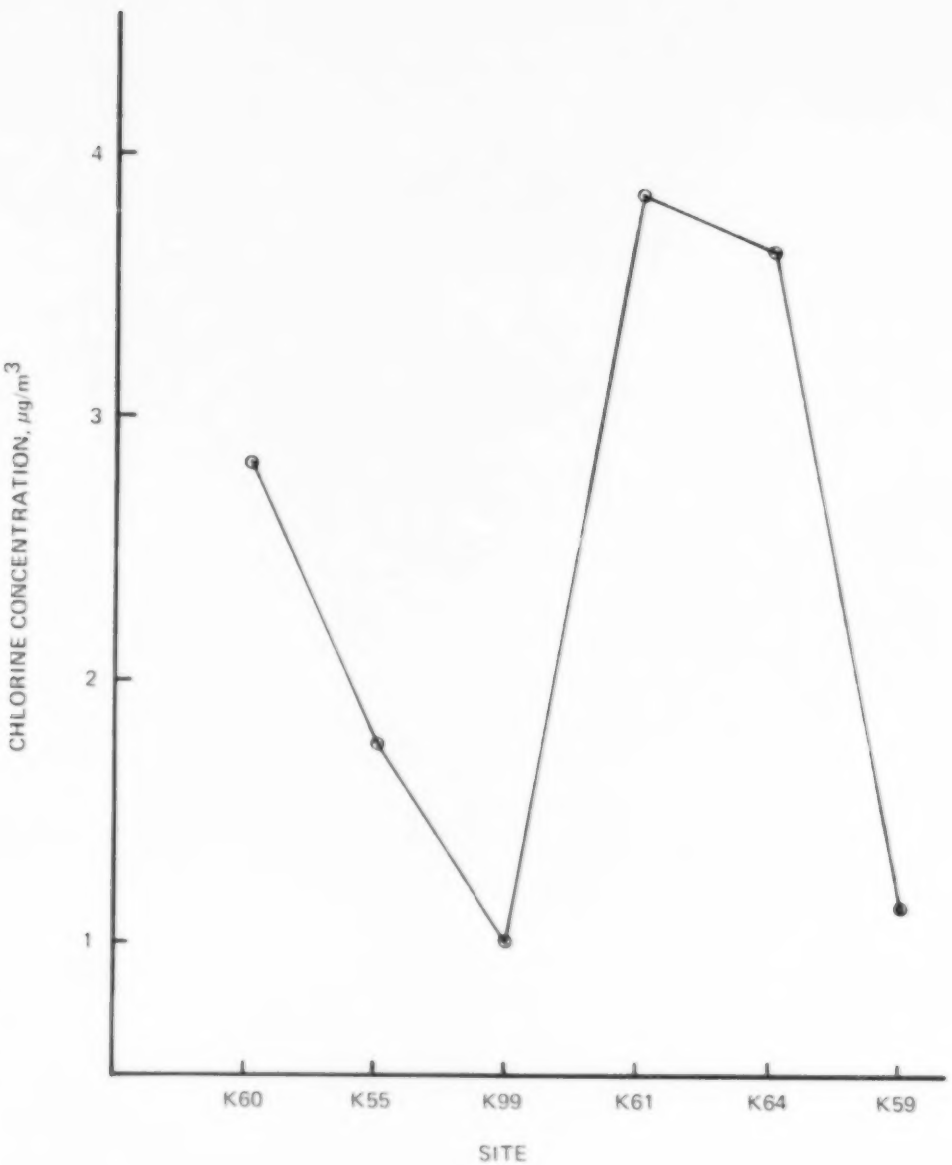

Figure 24. Average concentration of chlorine by site (northerly winds)

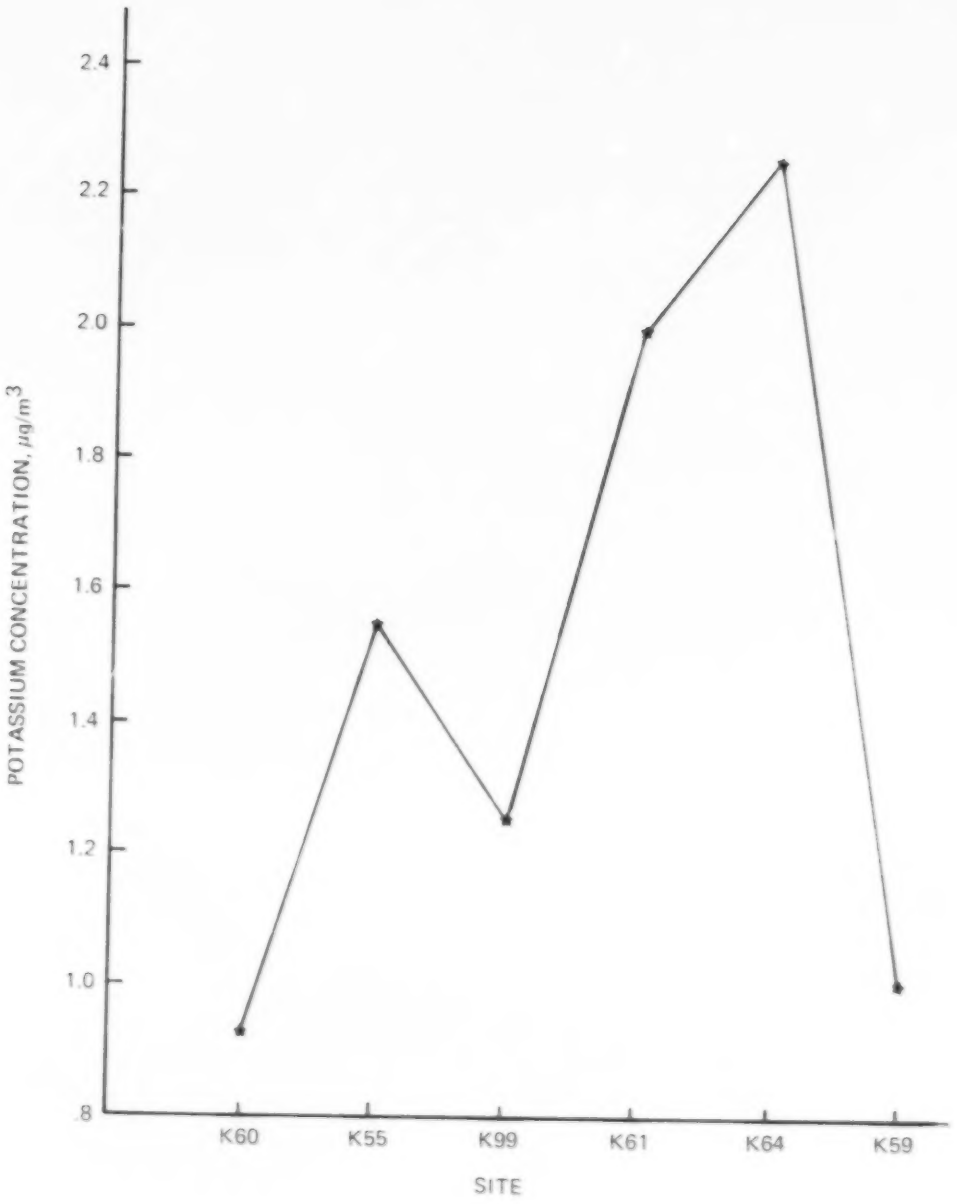

Figure 25. Average concentration of potassium by site (northerly winds)

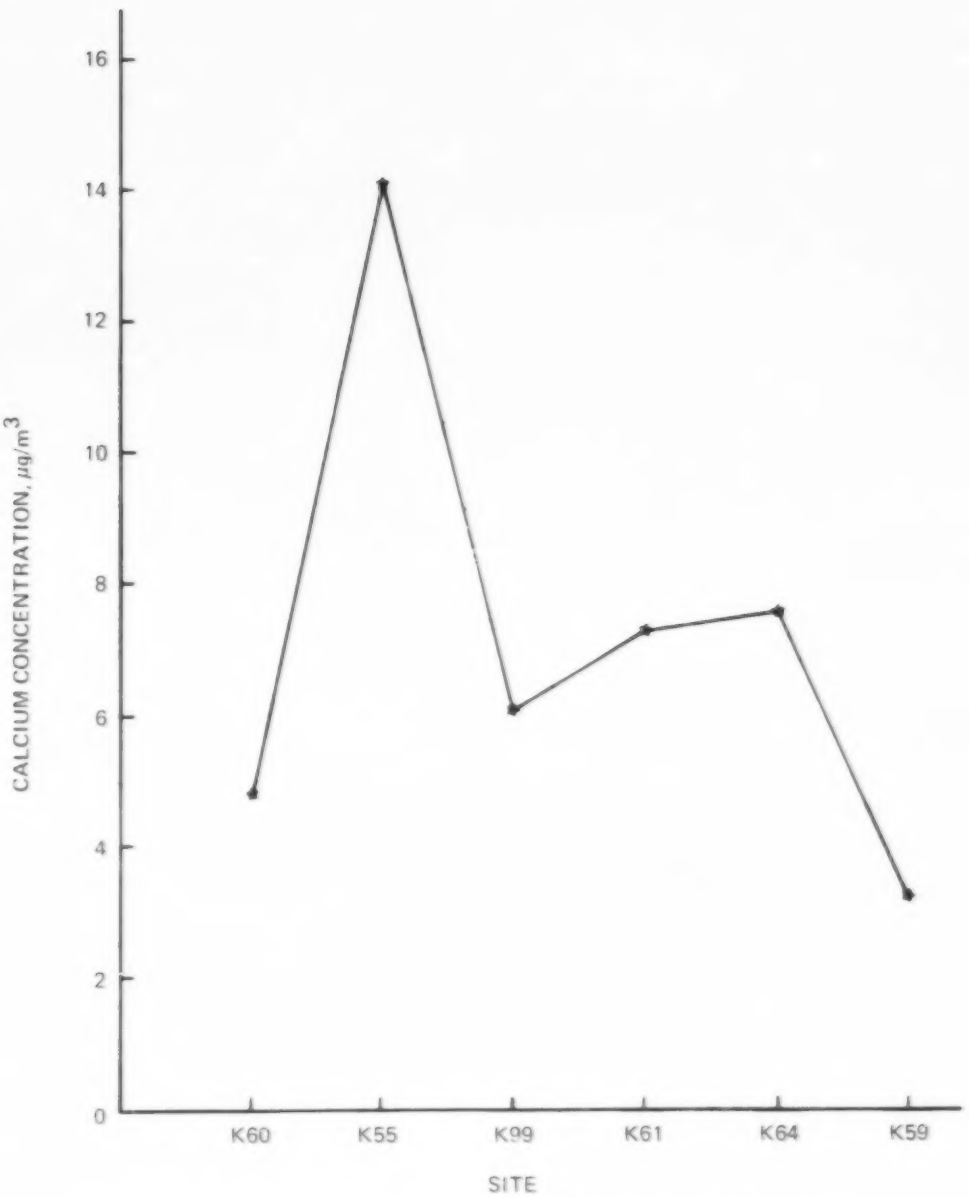

Figure 26. Average concentration of calcium by site (northerly winds)

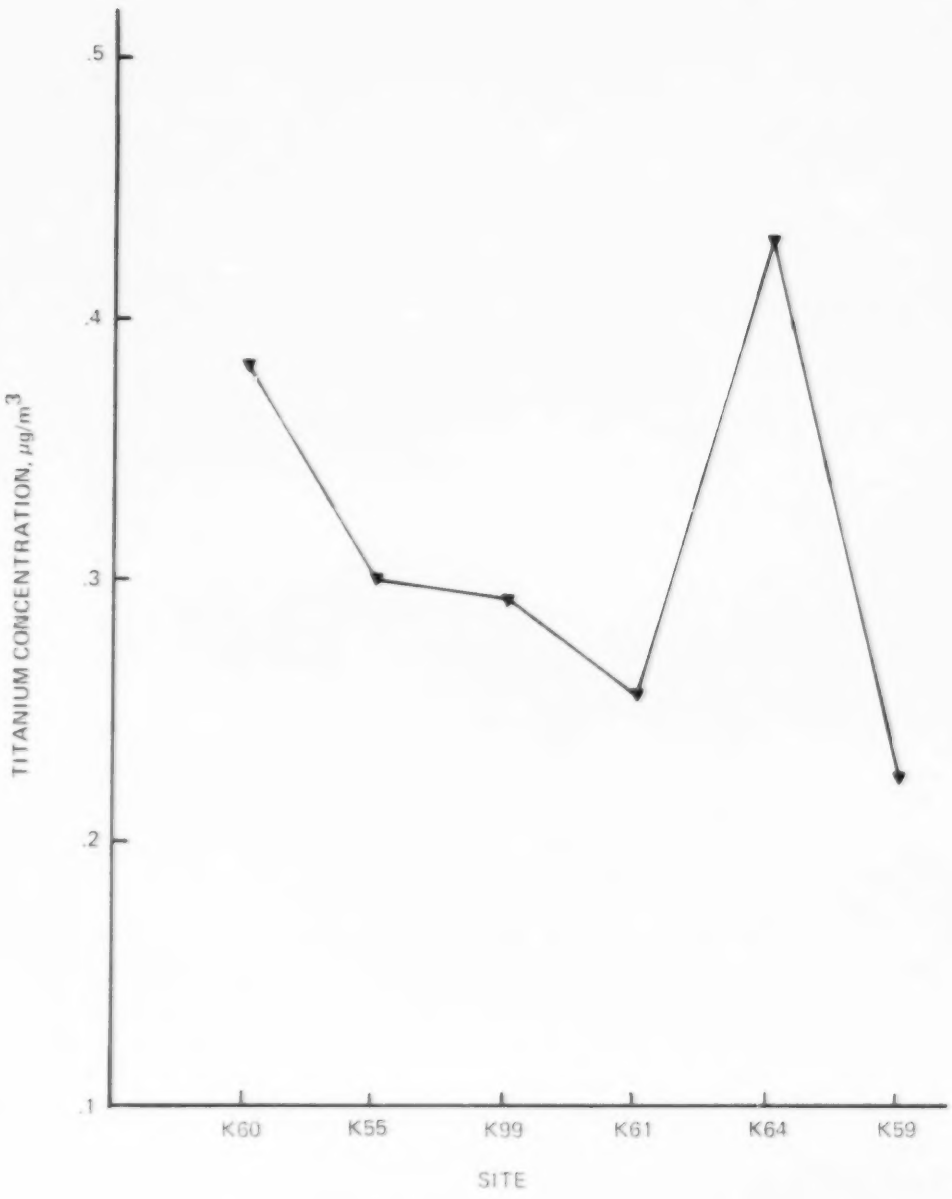

Figure 27. Average concentration of titanium by site (northerly winds)

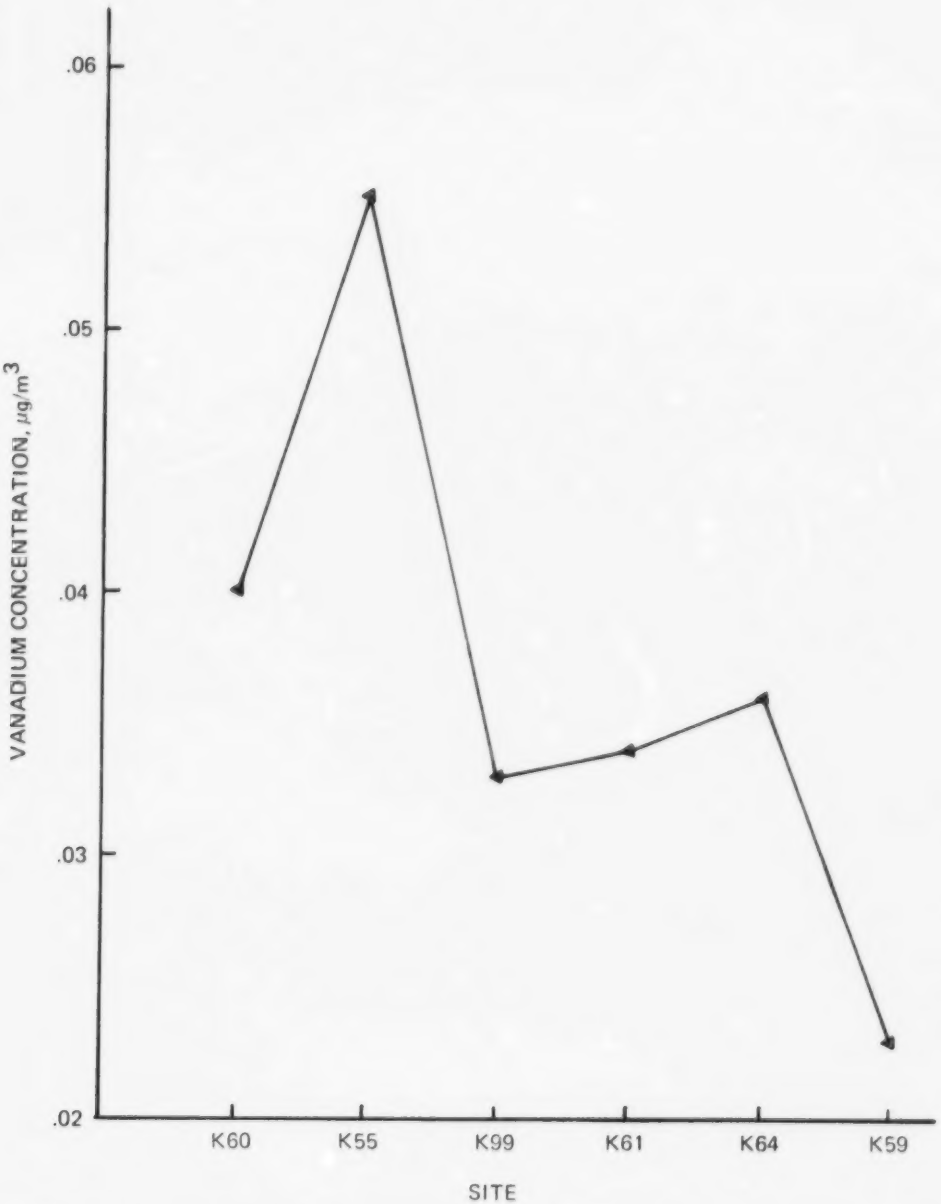

Figure 28. Average concentration of vanadium by site (northerly winds)

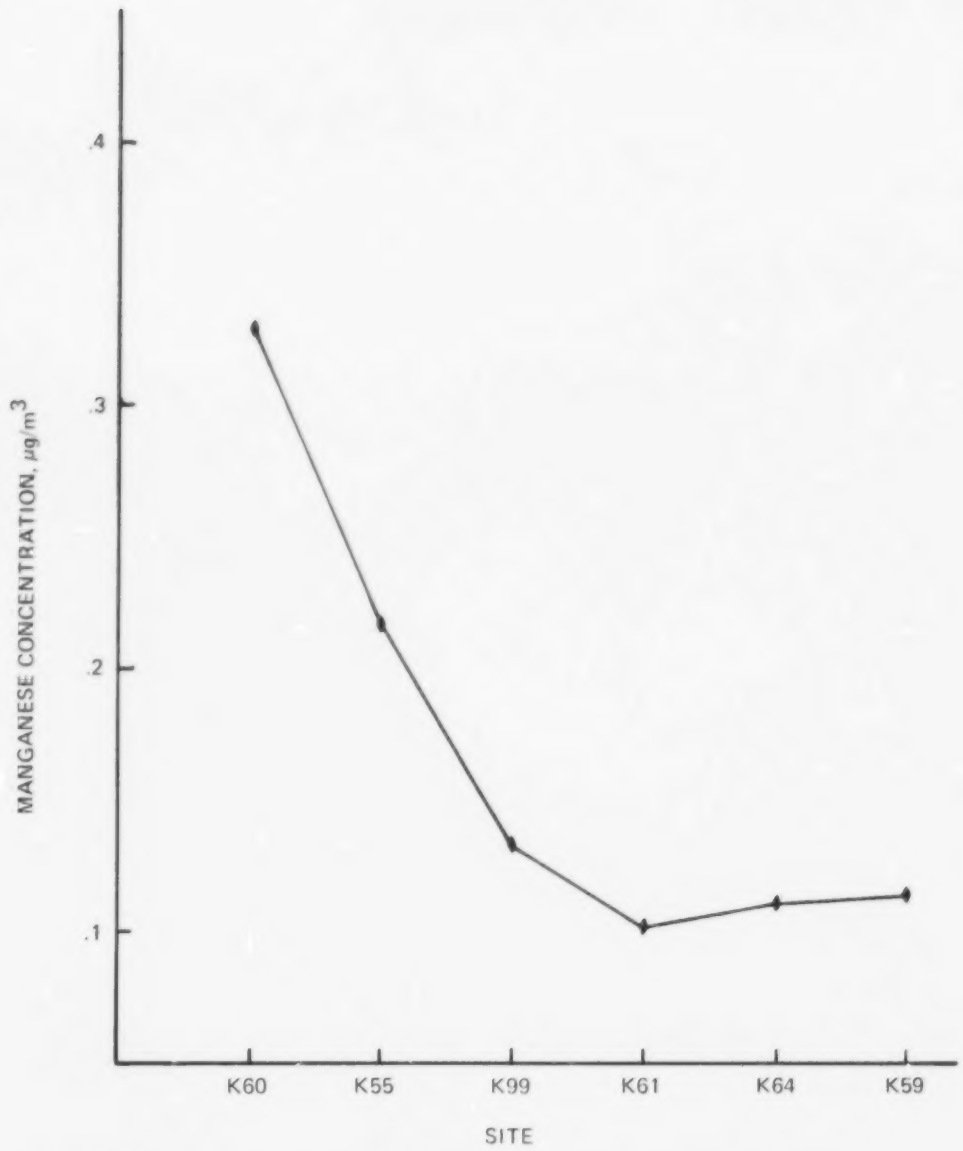

Figure 29. Average concentration of manganese by site (northerly winds)

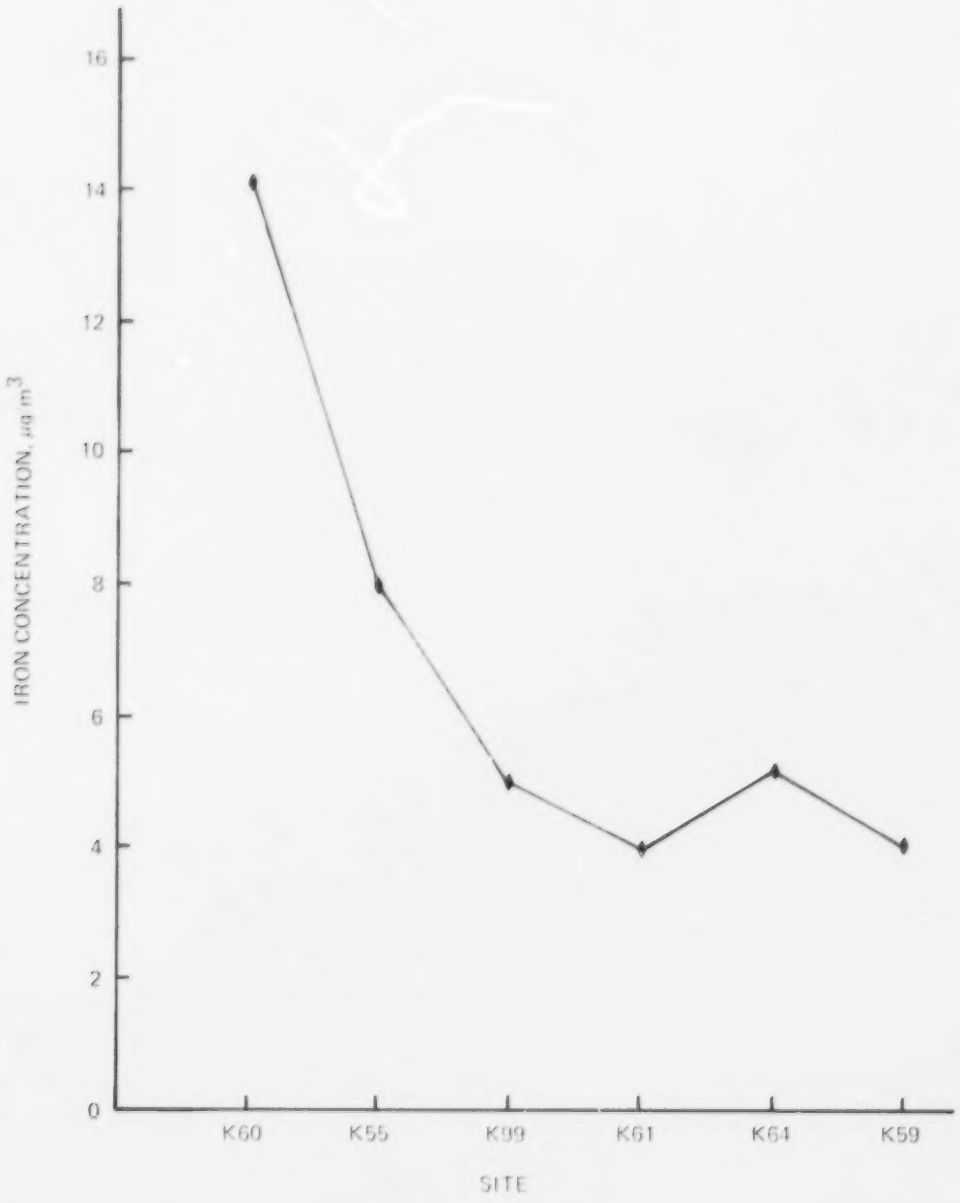

Figure 30. Average concentration of iron by site (northerly winds)

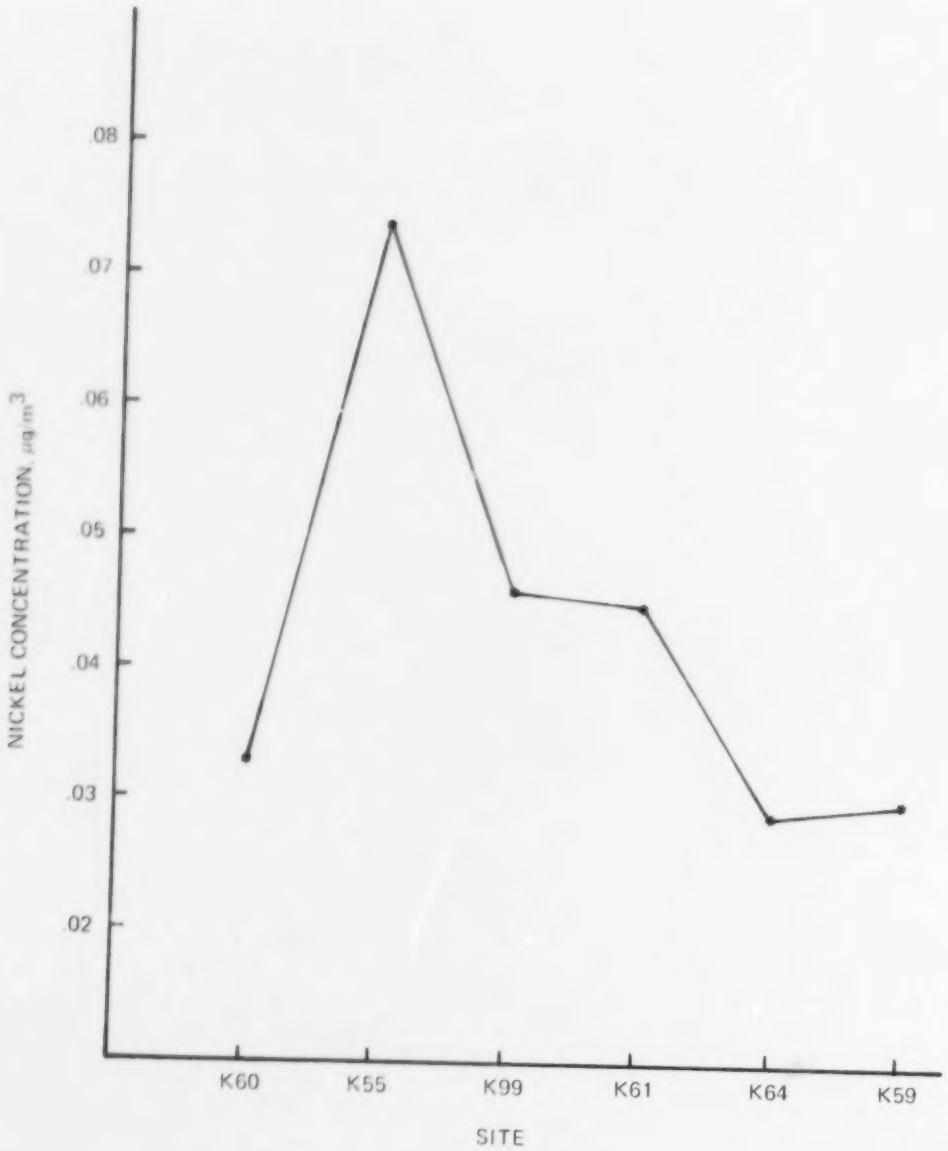

Figure 31. Average concentration of nickel by site (northerly winds)

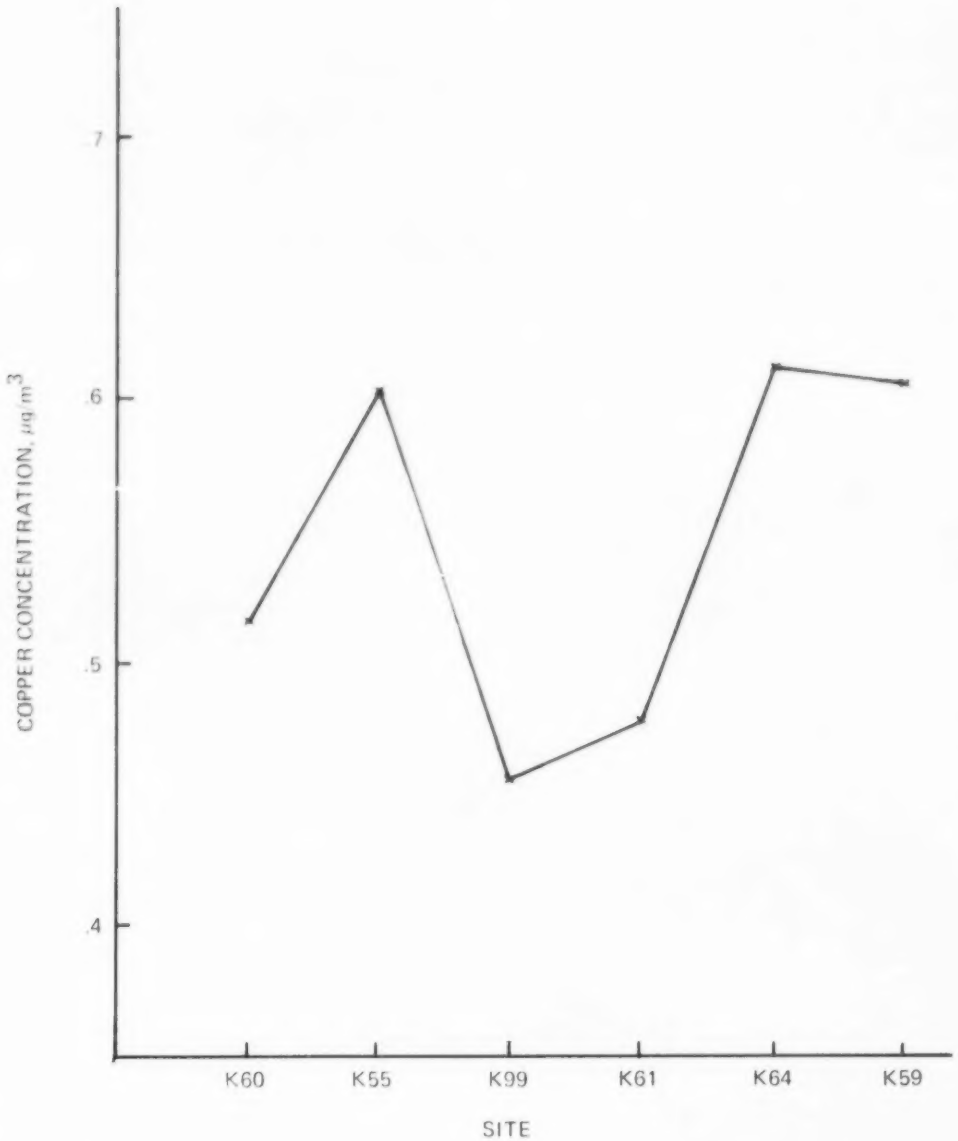

Figure 32. Average concentration of copper by site (northerly winds)

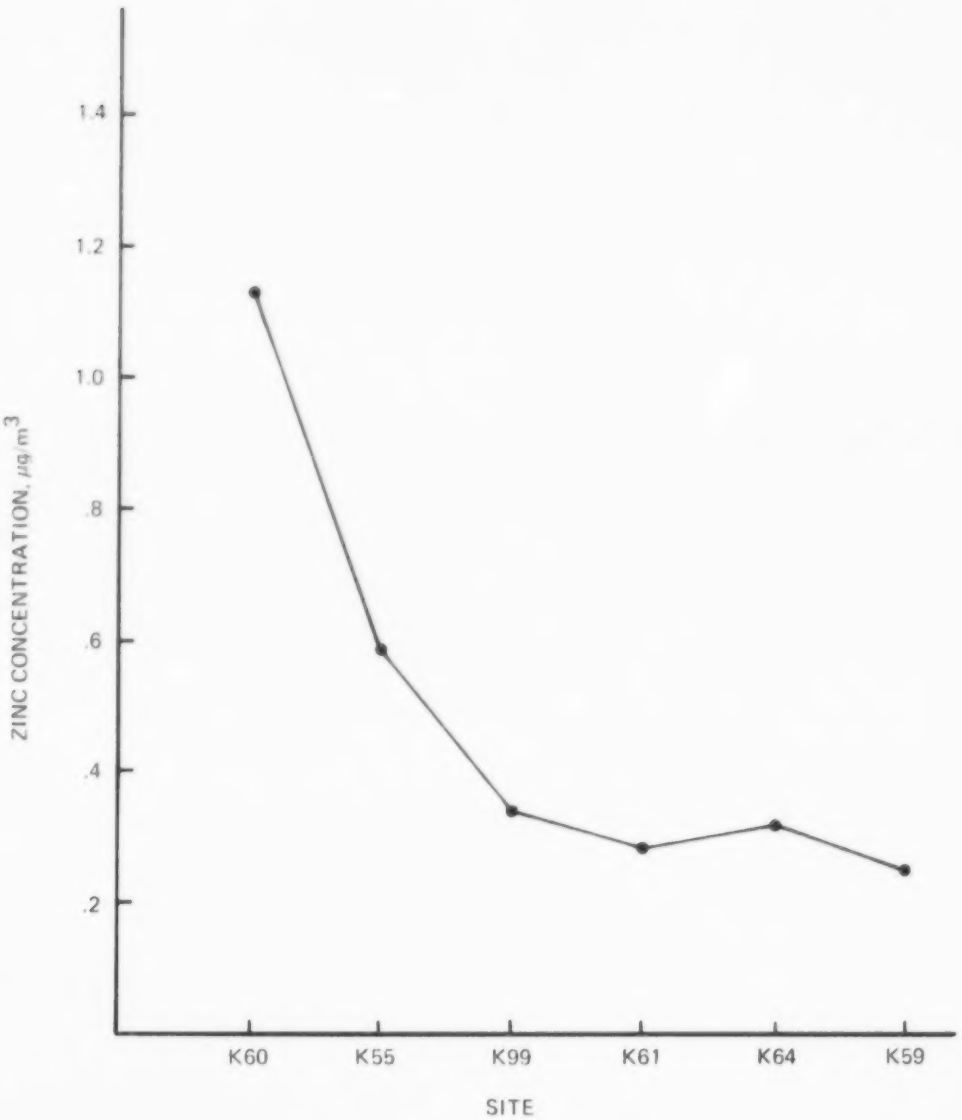

Figure 33. Average concentration of zinc by site (northerly winds)

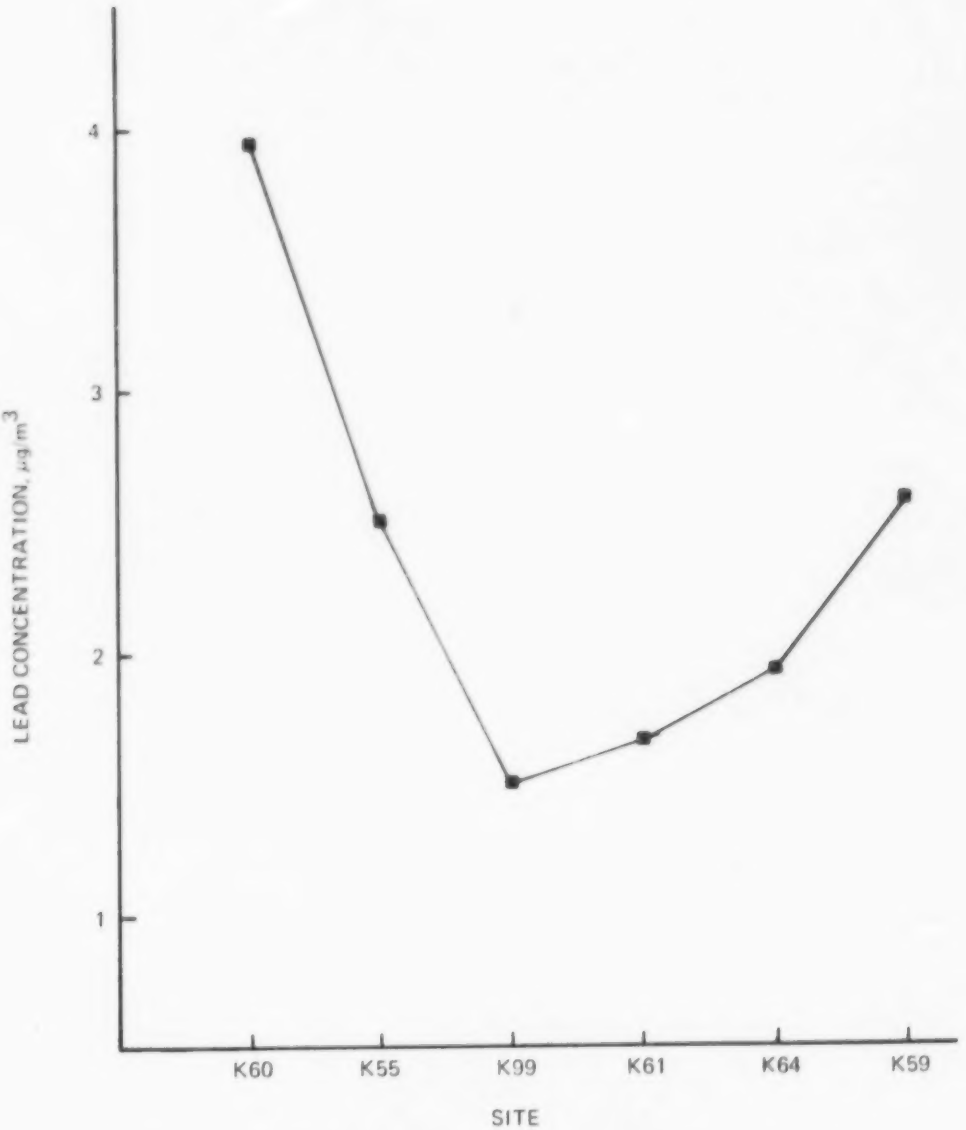

Figure 34. Average concentration of lead by site (northerly winds)

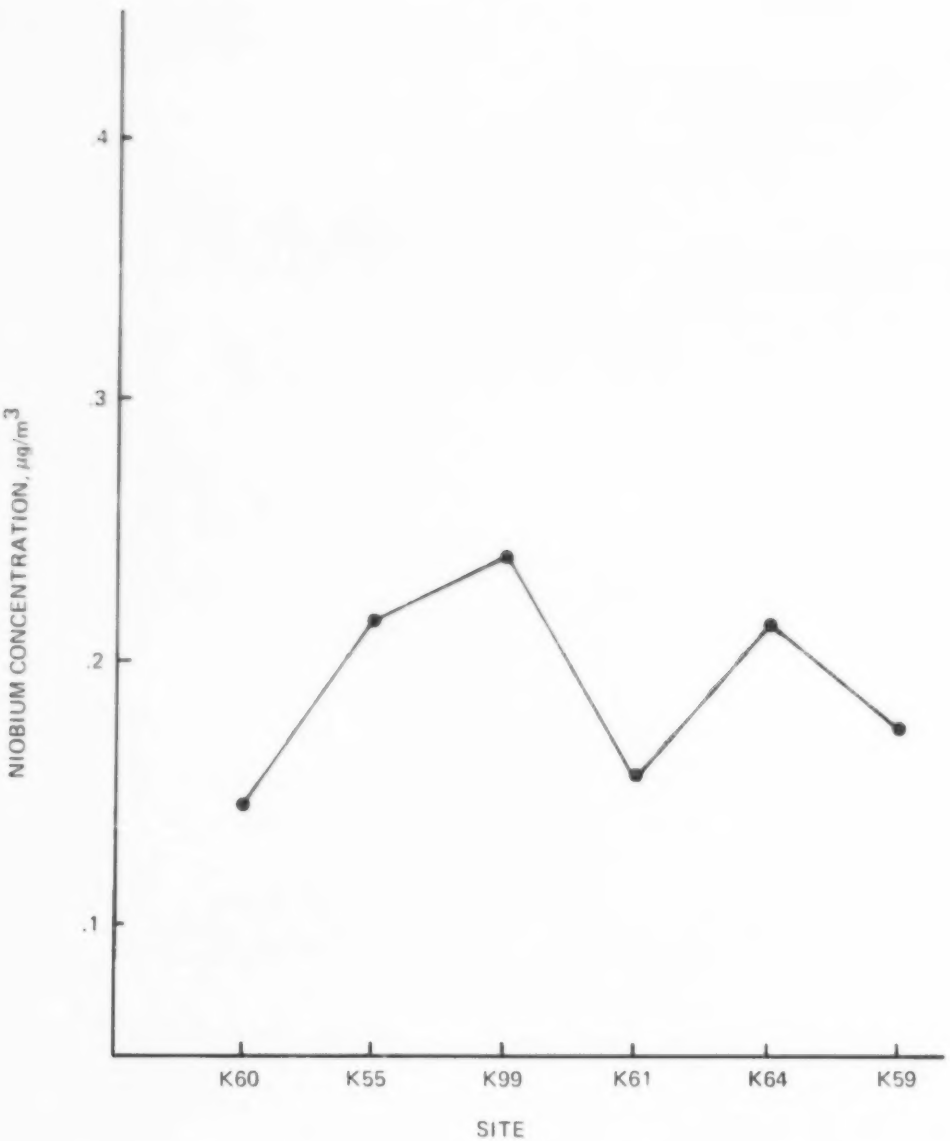

Figure 35. Average concentration of niobium by site (northerly winds)